

SPECTROPHOTOMETRIC STUDIES OF B, A AND F TYPE STARS

INAUGURAL DISSERTATION

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YNGVE ÖHMAN

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ALMQVIST & WIKSELLS BOKTRYCKERI-A.-B.

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FIL. LIC., VÄSTM.

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YNGVE ÖHMAN

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Introduction.

The present investigation has been carried out at the Upsala Observatory during the last three years. It is a part of the general spectrophotometric work on stars in the Greenwich polar zone which is in progress at Upsala and Stockholm. The paper presented here deals mainly with B, A and F type stars between 65° and 70° declination.

In a series of papers LINDBLAD¹ has developed methods for determining stellar luminosities by the use of short objective prism spectra, and the methods have been applied by him partly to some regions in the Greenwich polar zone and partly to bright stars scattered over the north celestial hemisphere. As to early type stars SCHALÉN² has contributed to the development of these methods and applied them extensively to stars in bright and dark galactic regions. PETERSSON's³ study of stars in the Carrington zone is another spectrophotometric work carried out according to the same principles.

The luminosity criteria introduced by LINDBLAD consist, as regards early type stars, mainly in a special luminosity classification based on the intensities and wings of the hydrogen lines and on colour. As to late type stars, the strength of the cyanogen bands and the colour have been measured and used to determine the absolute magnitudes. In the works referred to above the spectra were always kept

¹ B. LINDBLAD, Spectrophotometric methods for determining stellar luminosity, Mount Wilson Contr. No. 228, Ap. J. 55, p. 85, 1921.

B. LINDBLAD, Spectrophotometric determinations of stellar luminosities, Nova Acta Reg. Soc. Scient. Upsal., Ser. IV, Vol. 6, No. 5, 1925.

B. LINDBLAD, Researches based on determinations of stellar luminosities (second paper). Ibid. (Volumen extra ordinem editum 1927). Medd. Astr. Observ. Upsala. No. 11, 1926.

B. LINDBLAD och C. SCHALÉN, The luminosities, individual parallaxes, and motions of B and A type stars, Arkiv för matem., astr. o. fys. 20 A, No. 7, Medd. etc. Upsala No. 17, 1927.

B. LINDBLAD, On the absolute magnitudes and parallaxes of bright stars determined by the cyanogen criterion, Kungl. Svenska Vetenskapsakad. Handl., Ser. III., Band 4, No. 5, Medd. etc. Upsala No. 28, 1927.

² C. SCHALÉN, Spectrophotometric determinations of absolute magnitudes of B and A type stars, Arkiv etc. 19 A, No. 33. Medd. etc. Upsala, No. 10, 1926.

C. SCHALÉN, The space distribution of B and A type stars in bright and dark galactic regions, Kungl. Svenska Vetenskapsakad. Handl., Ser. III., Band 6, No. 6, Medd. etc. Upsala No. 37, 1928.

³ H. PETERSSON, The distribution of distances and velocities of stars in the Carrington zone on the basis of spectrophotometric analysis, Medd. etc. Upsala No. 29, 1927.

narrow. A series of exposures was taken and in the measurement of the intensity ratio between two spectral regions the exposure ratio corresponding to equal density of the two regions was estimated and used as measure of the effect looked for.

In 1927 I made an attempt to use the SCHILT photometer for the study of the above luminosity effects.¹ The photometer was shown to be very suitable for this purpose when using widened spectra. A method was developed for measuring line intensities with this photometer and the same method has been used in the work presented here. A brief account of some results of the present investigation was already given in March this year.² 882 B, A and F type stars in the Greenwich zone have been investigated and 15 bright F stars and 43 stars in the Pleiades as well. The purpose of this work is mainly a study of the relation between hydrogen line intensity, colour, and absolute luminosity. The photometric measures give a more objective and exact method than the classification does. It has been found that the intensity of the hydrogen lines, combined with colour, gives good information on luminosity not only for B0—A3 stars but also for A5—F8 stars. Indeed, the luminosities of most of the stars have thus been determined. Besides the hydrogen lines $H\gamma$ and $H\delta$ also the Ca^+ line K has been studied. The colour-equivalent used is the difference in magnitude between the wavelengths 3912 Å and 4415 Å.

In presenting this paper I should like to take the occasion to express my sincere thanks to Professor Ö. BERGSTRAND, director of the Upsala Observatory, for the great and kind interest he always has shown to me during the pleasant years I spent at the observatory both as student and as assistant.

To Professor B. LINDBLAD, director at the Stockholm Observatory, I will also express my sincere thanks, as he originally introduced me to the subject of stellar spectra, and ever since has shown a lively interest to my investigations, and often given me valuable advice and criticism.

I am also much indebted to Professor H. VON ZEIPPEL with whom I have had many interesting and instructive talks about questions related to theoretical astrophysics.

Finally I am under obligation to Professor K. LUNDMARK and Dr. C. SCHALÉN as well as to other Swedish astronomers for their helpfulness in various respects.

Upsala August 1930.

Yngve Öhman.

¹ Y. ÖHMAN, Photometric studies of effects of luminosity and colour in short stellar spectra, Arkiv etc., 20 A, No. 23, Medd. etc. Upsala No. 33, 1927.

² Y. ÖHMAN, The intensity of the hydrogen lines as criterion of luminosity for B, A and F type stars, Arkiv etc. 22 B, No. 3, Medd. etc. Upsala No. 47, 1930.

CHAPTER I.

On the General Problem of Interpreting Stellar Spectra by Means of Photometric Analysis. A Short Survey.¹

In recent years much attention has been paid to the photometric analysis of stellar spectra. A classification based merely on an inspection of the general appearance of the spectra is nowadays not sufficient when dealing with many problems of astrophysics. A precise photometric analysis may give us information as to the general intensity distribution in the continuous spectrum and thus serve as a basis for determinations of stellar temperatures. It also opens the way for a detailed knowledge of the intensities and contours of spectral lines and the strength of absorption bands, and is thus of the greatest value in the general study of stellar atmospheres and indirectly for determinations of stellar luminosities and distances.

1. The earlier spectrophotometric determinations of stellar temperatures were based on visual measurements.² The photographic method has, however, many advantages and is nowadays always preferred. It was applied on a large scale for the first time by ROSENBERG³ in 1914. The measurements themselves are generally not difficult to perform in such investigations but there are several other difficulties to overcome in the deduction of final temperatures. When comparing widely separated

¹ For an exhaustive treatment of this subject reference is made to the following works:

CECILIA PAYNE, *Stellar atmospheres*, Cambridge, Mass. 1925.

A. BRILL, *Spektralphotometrie*, Handbuch der Astrophysik, Band II/1, Berlin 1929.

—, *Die Temperaturstrahlung der Fixsterne*, Zeitschr. für Physik 52, p. 767, 1929.

E. A. MILNE, *Thermodynamics of the stars*, Handbuch der Astrophysik, Band III/1, Berlin 1930.

—, *The structure and opacity of a stellar atmosphere*, Bakerian Lecture, Phil. Trans. Royal. Soc. of London, Ser. A, Vol. 228, 1929.

A. PANNEKOEK, *Die Ionisation in den Atmosphären der Himmelskörper*, Handbuch der Astrophysik, Band III/1, Berlin 1930.

² H. C. VOGEL, *Resultate spektralphotometrischer Untersuchungen*, Monatsberichte der Kgl. Preussischen Akademie der Wissenschaften zu Berlin 1880, p. 801.

J. WILSING u. J. SCHEINER, *Temperaturbestimmung von 109 helleren Sternen aus spektralphotometrischen Beobachtungen*. Publ. Astroph. Obs. Potsdam No. 56, 1909.

J. WILSING, J. SCHEINER u. W. MÜNCH, *Effektive Temperaturen von 199 helleren Sternen nach spektralphotometrischen Messungen*, Ibid., No. 74, 1919.

³ Compare: BRILL, loc. cit.

wavelengths, as is here the case, the measures must be reduced to true intensities and this often introduces a good deal of uncertainty. Besides this it is often difficult to define the continuous spectrum if absorption lines and bands are present. Moreover, the intensity distribution often deviates more or less from PLANCK's formula and measurements from different spectral regions will give conflicting results.¹ The »colour temperature» or »gradient temperature»² determined from the shape of the energy-curve for the continuous spectrum thus generally deviates from the »effective temperature» corresponding to the net flux of energy from the stars and calculated according to STEFAN's law. Indeed for many purposes it seems better not to calculate a temperature but to use the simple temperature-equivalent involved in the intensity ratio between two widely separated wavelengths. At least it seems necessary to use the same spectral regions in order to obtain quite equivalent temperatures. Important investigations on colour and gradient temperatures are in progress at Edinburgh³, Greenwich⁴, Göttingen⁵ and Harvard⁶.

2. The problem of measuring line intensities presents mainly other difficulties than the problem of determining colour temperatures, because the wavelengths compared here are too close together. In this case also, however, it may sometimes be difficult to define the continuous background to which the line measurements are to be referred. The greatest difficulties are no doubt involved in the determinations of the very line contours. Serious errors may thus be introduced by failing sharpness of the spectra caused by too small a dispersion, bad focus and unsteady weather conditions. Also the EBERHARD development effect may in certain circumstances be dangerous.

The first determinations of line intensities were based on pure estimates in an arbitrary scale. ROWLAND's intensities of the solar lines gives an example of such estimates. Miss MAURY⁷ first tried this method on stellar spectra, but as one often wants here to compare the same line for different stars, the problem becomes more

¹ Compare: BRILL, loc. cit. on page 5.

² For the distinction between these kinds of temperatures see:

H. SIEDENTOPF, Grundlagen der Kosmogonie, Veröff. Univ.-Sternwarte Göttingen, Heft 3, 1928.

³ R. A. SAMPSON, On the estimation of the continuous spectrum of stars, Monthly Notices 83, p. 174, 1923.

R. A. SAMPSON, Effective temperatures of sixty-four stars. Ibid., 85, p. 212, 1925.

⁴ W. M. H. GREAVES and C. R. DAVIDSON, Preliminary note on the determination of effective stellar temperatures by the »prism-crossed-by-grating» method, Monthly Notices 86, p. 33, 1925.

W. M. H. GREAVES, C. R. DAVIDSON and E. MARTIN, The relative effective temperatures of twenty-two stars of early type, Ibid. 87, p. 352, 1927.

W. M. H. GREAVES, C. R. DAVIDSON and E. MARTIN, The colour temperatures of twenty-four stars, suitable for use as spectro-photometric standards, Ibid. 90, p. 104, 1929.

⁵ KIENTLE, Untersuchungen über die Intensitätsverteilung in Sternspektren. Nachr. der Gesellsch. der Wissensch. zu Göttingen, Matem.-phys. Klasse, 1925.

⁶ B. P. GERASIMOVIC, Spectrophotometric temperatures of early stars, Harv. Circ. 339, 1929.

L. HUFNAGEL, Temperatures of giants and dwarfs, Ibid. 343, 1929.

⁷ ANTONIA C. MAURY, Spectra of bright stars etc. Harvard Annals 28, Part I, 1897.

complicated. Such estimates have been made recently, also, notably at Harvard¹, and a very interesting method for calibrating such scales by means of known intensity relations in multiplets has been put forward by RUSSELL, ADAMS and MOORE².

Estimates of the relative intensities of adjacent lines in the same spectrum have attained importance in connection with spectroscopic determinations of absolute magnitudes. The accurate determinations carried out at Mount Wilson³ and Victoria⁴ have clearly shown that good results can be obtained by such estimates. A more objective method for comparing pairs of spectral lines has been developed more recently at the Norman Lockyer Observatory⁵. All these methods have, however, the common weakness that we do not quite know the physical significance of such estimates and measurements, and of course precise photometry is from many points to be preferred.

A photometric investigation of the contours of the *H* and *K* lines in the solar spectrum was carried out by SCHWARZSCHILD in 1914⁶. Measurements of stellar absorption lines were at first tried by BOTTLINGER⁷ and later by KOHLSCHÜTTER⁸ and SHAPLEY⁹, but the agreement between the different measurements was not always satisfactory. In recent years, however, the methods have been considerably improved and very accurate results have been obtained. Line intensities have been measured, especially by Harvard astronomers¹⁰, and also by PANNEKOEK¹¹, CH'ING-

¹ Compare: CECILIA PAYNE, loc. cit. on page 5.

² H. N. RUSSELL, W. S. ADAMS and CHARLOTTE E. MOORE, A calibration of Rowland's scale of intensities for solar lines. *Astroph. Journal* 68, p. 1, 1928.

W. S. ADAMS and H. N. RUSSELL, Preliminary results of a new method for the analysis of stellar spectra, *Ibid.*, p. 9, 1928.

³ W. S. ADAMS, A. H. YOY, G. STRÖMBERG and CORA G. BURWELL, The parallaxes of 1646 stars derived by the spectroscopic method, *Astroph. Journal* 53, p. 13, 1920, Mount Wilson Contr. No. 199, 1920.

⁴ R. K. YOUNG and W. E. HARPER, The absolute magnitudes and parallaxes of 1105 stars, *Publ. of the Dominion Astroph. Observatory*, Vol. III, No. 1, 1924.

⁵ W. J. S. LOCKYER, The use of a graduated wedge in stellar classification and parallax work, *Monthly Notices* 82, p. 226, 1922.

⁶ K. SCHWARZSCHILD, Über Diffusion und Absorption in der Sonnenatmosphäre, *Sitzungsber. d. Pr. Ak. d. Wiss.* 47, p. 1183, 1914.

⁷ F. K. BOTTLINGER, Über die Intensitätsverteilung innerhalb der Spektrallinien von Sternen, *Astr. Nachr.* 195, p. 117, 1913.

⁸ A. KOHLSCHÜTTER, Messungen von Linienintensitäten in Sternspektren, *Astr. Nachr.* 220, p. 325, 1924.

⁹ H. SHAPLEY, Preliminary report on the brightness of absorption lines, *Harv. Bull.* 805, 1924.

¹⁰ CECILIA H. PAYNE, F. S. HOGG, EMMA WILLIAMS, a great number of papers. *Harv. Bull.* 837, 843, 858, 867, 874; *Harv. Repr.* 28, 43, 46, 48, 55, 62; *Harv. Circ.* 301—309, 334, 337, 348; (1926—1930).

¹¹ A. PANNEKOEK, The determination of absolute line intensities in stellar spectra. *Bull. Astr. Inst. Netherlands* IV, p. 1, 1927.

SUNG YÜ¹ and ELVEY². Line photometry in the solar spectrum has in recent times been performed by VON KLÜBER³, UNSÖLD⁴ and MINNAERT⁵.

The spectra used for these investigations were taken in a rather high dispersion in order to reduce the influence of disturbing factors connected with failing sharpness of the spectra. The measurements of wide spectral line, e.g. the hydrogen lines of A stars, are comparatively free from such influence but in the case of narrow lines the measurements often depend to a high degree upon the apparatus used. In order to derive the line intensities, the spectra were generally analyzed by means of a self-registrering microphotometer, and the tracings then transformed to corresponding intensity diagrams with the help of some sort of intensity scale, giving the relation between photographic density and intensity.

A detailed analysis of line contours requires, as was mentioned above, spectra of rather high dispersion. Only comparatively bright stars may, however, be reached by such a method. When studying absorption bands, on the other hand, it is often advantageous to use short spectra, as exemplified by the photometric work carried out at Upsala⁶ on the cyanogen absorption in late type spectra. I have shown that intensities may also be derived from such short spectra for the hydrogen lines and the K-line. The quantities to be reached by such methods give of course not true contours but a value of the total loss of light in the lines. The present investigation is carried out according to these principles. The great advantage of using short spectra is that faint stars also may be reached and a more natural and rich selection is thus possible.

3. The theoretical interpretation of stellar spectra has in recent time become more and more clarified. The well known relation between spectral type and colour had already revealed the spectral sequence as a decreasing temperature series. In connection with this, the studies of Sir NORMAN LOCKYER concerning »enhanced lines» and »arc lines» and their different intensity variations within the spectral scale contributed in several points to a true view of stellar spectra. With the appearance of BOHR's theory and after the development of the theory of thermal

¹ CH'ING-SUNG YÜ, A proposed spectrophotometric method for determining the absolute luminosities of class A stars, Lick Observ. Bull. 380, 1926.

² C. T. ELVEY, The contours of the hydrogen lines of Sirius and of other A-stars. *Astroph. Journal* 68, p. 145, 1928.

³ H. VON KLÜBER, Quantitative Untersuchungen an Absorptionslinien im Sonnenspektrum. *Zeitschr. für Physik*, 44, p. 481, 1927.

⁴ A. UNSÖLD, Über die Struktur der Fraunhoferschen Linien und die Dynamik der Sonnenschromosphäre. *Ibid.*, 44, p. 793, 1927.

A. UNSÖLD, Über die Balmerserie des Wasserstoffs im Sonnenspektrum. *Ibid.*, 59, p. 353, 1930.

⁵ M. MINNAERT, Die Intensität innerhalb Fraunhoferschen Linien. *Ibid.*, 45, p. 610, 1927.

⁶ Loc. cit. in the Introduction.

How well these bands come to view in the Upsala spectra can be seen from some microphotometric tracings given by the writer:

Y. ÖHMAN, Photographic density-diagrams of short stellar spectra. *Arkiv etc.* 19 B, No. 6, Medd. Astr. Observ. Upsala, No. 5, 1926.

ionization by SAHA¹, DARWIN, FOWLER and MILNE², the interpretation of stellar spectra has been put on a sure basis.

A certain spectral line can appear in a stellar spectrum only if the atoms giving rise to this line are in such a state as to absorb the line. The number of atoms in a certain state has been shown to be a function of the temperature and pressure in the stellar atmosphere and the excitation potential corresponding to this state. As the intensity of an absorption line could be considered a measure of the number of absorbing atoms above the photosphere contributing to this line, the way was open for determinations of temperature and pressure by means of line photometry. Investigations along such lines have been in progress chiefly at Harvard³. The surface gravity is connected to the pressure gradient in the stellar atmospheres according to the well known equation of mechanical equilibrium. In that way the surface gravity enters the formulae for line intensities. As there exists a certain relation between the luminosities and the masses of the stars⁴, the spectroscopic methods for determining absolute magnitudes have in this way found a logical basis.

The first theory of the formation of stellar absorption lines was advanced by SCHUSTER⁵ as early as 1905. He studied the lines as arising in an absorbing and scattering atmosphere placed in front of the photosphere. Though this treatment of the problem involved a considerable simplification of the true conditions, it gave in several respects the essential features of the process. Later on, the theory for the formation of absorption lines has been developed by STEWART⁶, UNSÖLD⁷, MILNE⁸, EDDINGTON⁹ and WOLLEY¹⁰. The considerable width of certain stellar absorption lines has always been a difficult problem. According to UNSÖLD the width seems, however, above all to be due to »radiative damping», and he has succeeded in de-

¹ MEGH NAD SAHA, Ionisation in the solar chromosphere, *Phil. Mag.* 40, p. 472, 1920.

—, On a physical theory of stellar spectra. *London R. S. Proc.* 99, p. 135, 1921.

² R. H. FOWLER and E. A. MILNE, The intensities of absorption lines in stellar spectra, *Monthly Notices* 83, p. 403, 1923.

R. H. FOWLER and E. A. MILNE, 2nd Paper. *Ibid.* 84, p. 499, 1924.

R. H. FOWLER, *Statistical Mechanics*, Cambridge 1929.

E. A. MILNE, Bakerian Lecture, *loc. cit.* on page 5.

³ CECILIA PAYNE, *loc. cit.*

⁴ A. S. EDDINGTON, *The internal constitution of the stars*. Cambridge 1926.

⁵ A. SCHUSTER, Radiation through a foggy atmosphere. *Astroph. Journal* 21, p. 1, 1905.

⁶ J. Q. STEWART, The width of absorption lines in a rarefied gas, *Astroph. Journal* 59, p. 30, 1924.

⁷ A. UNSÖLD, *loc. cit.* on page 8.

⁸ E. A. MILNE, The theoretical contours of absorption lines in stellar atmospheres. *Monthly Notices* 89, p. 3, 1928.

—, Bakerian Lecture, 1929.

⁹ A. S. EDDINGTON, *The internal constitution of the stars*. Cambridge 1926.

—, The formation of absorption lines, *Monthly Notices* 89, p. 620, 1929.

¹⁰ R. WOOLLEY, On the central intensities of some absorption lines in the solar spectrum. *Monthly Notices* 90, p. 170, 1929.

2—30736. *Nova Acta Reg. Soc. Sc. Ups., Ser. 4, Vol. VII. N:o 3. Impr.* 27/10 1930.

ducing theoretical line contours by applying the theory of radiative equilibrium¹ and using a theoretical expression for the scattering coefficient. The strength of a line is thus found to depend on the number of »effective» atoms down to the photospheric radiating surface or, in other words, the breadth is simply attributed to an »abundance effect». Milne has given a valuable contribution to this theory and analysed what is really the meaning of the phrase »above the photosphere». He has shown that the photospheric opacity is a chief factor in this connection and that the way in which the opacity varies with temperature and electron pressure determines in several cases the dependence between line intensity and luminosity. The hydrogen lines for instance will according to this theory be intimately correlated with luminosity on the low temperature side of the maximum.

There is generally a very good agreement between the theoretical line contours deduced by UNSÖLD and the contours found by observation. But in the case of the hydrogen lines, the agreement is not satisfactory. Here, perhaps, we have other causes contributing to the great width of the lines and according to O. STRUVE² the Stark effect seems here to play an important rôle.³ As the electric field is connected with the partial electron pressure, the Stark broadening may thus also be connected with the absolute magnitude.

Line-contours may also be influenced by an axial rotation of the stars, as has been shown by SHAJN and STRUVE.⁴

CHAPTER II.

Apparatus and Material.

All plates used for the present investigation have been taken with 15 cm. Zeiss Heyde astrograph of the Upsala Observatory. This instrument has two photographic tubes with almost identical Zeiss triplet object glasses of apertures 15 cm. and focal lengths 150 cm. Most spectra have been taken with the tube No. 1 and a Zeiss objective prism of $9^{\circ}.7$ refracting angle. The spectra obtained in this way are very short, only 1.37 mm. between $H\gamma$ and $H\epsilon$. For a certain purpose, a few plates have also been taken with the tube No. 2 in conjunction with a $10^{\circ}.0$ prism from Zeiss, belonging to the Observatory at Lund. This prism gives very nearly twice the dispersion of the Upsala prism.

¹ K. SCHWARZSCHILD, loc. cit. on page 7.

² O. STRUVE, The Stark effect in stellar spectra. *Astroph. Journal* 69, p. 173, 1929.

³ UNSÖLD has recently shown that the Stark effect is responsible for the width of the higher members of the Balmer series in the spectrum of the sun:

A. UNSÖLD, Über die Balmer serie des Wasserstoffs im Sonnenspektrum. *Zeitschr. für Phys.* 59, p. 353, 1930.

⁴ G. SHAJN and O. STRUVE, On the rotation of the stars, *Monthly Notices* 89, p. 222, 1929.

The instrument gives spectra of excellent quality and almost the whole 16×16 cm. plate field could be used. Only at one side, near the edge, the definition of the images is not quite good. The secondary spectrum of the object glasses is very favourable for studying spectra and sharp focus may at the same time be obtained for all wavelengths between $H\gamma$ and the K-line. The secondary spectrum of the object glass No. 1 has been described by LINDBLAD in connection with his researches on effective wavelengths.¹ A confirmation of his curve has been obtained in the present investigation in connection with the study of the influence of varying focal length on the line intensity measurements.²

All spectra used for the present investigation have been widened and the same methods have been employed as in my previous work. One of the plateholders was thus equipped with a micrometer screw and in order to obtain widened spectra a series of 14 images was taken, the distance between successive images being 0.015 mm. This method of broadening has been employed to the ordinary program plates. The spectra obtained in this way are of excellent quality, as disturbances connected with varying atmospheric refraction and faults in the adjustment of the instrument will not influence the sharpness of the spectra. Moreover the images are generally free from longitudinal stripes. Some spectra taken for special purposes have been widened with an eyepiece scale divided into 0.05 mm. In this case the guiding star was placed in succession on and half way between the scale graduations. (Focal length of the guiding telescope = 200 cm.) Finally, some spectra of bright stars have also been broadened with the instrument kept fixed, the broadening thus being produced by the diurnal motion.

As already mentioned, the present work includes mainly stars in the Greenwich zone between 65° and 70° declination. The part of this zone between $8^h 30^m$ and $13^h 30^m$ has been studied earlier by LINDBLAD, by means of narrow spectra³, and this part is not included in the present investigation. From Fig. 1 it is clear how the plates are situated in the zone. The circles denote the centres of plates and the figures give the plate numbers. The plates have been taken 40^m apart in right ascension. As the side of a plate corresponds to about 6° , successive plates cover each other by about $\frac{1}{3}$ of the plate area. A great number of stars thus appear on two plates and in this way the sensitiveness of the plates for different wavelengths may be compared. From several points of view, it would perhaps have been desirable to take the plates so close to each other that all the zone areas had been covered twice, but as the quality of the spectra is good enough to allow accurate measurements, even in the case of a single image, the arrangement employed was found to be the most convenient.

¹ B. LINDBLAD, Die photographisch effektive Wellenlänge als Farbenäquivalent der Sterne, Arkiv för matem., astr. o. fys. 13, No 26, p. 5, 1918.

² Compare page 34.

³ B. LINDBLAD, Medd. fr. Astr. Observ. Upsala, No. 11, 1926.

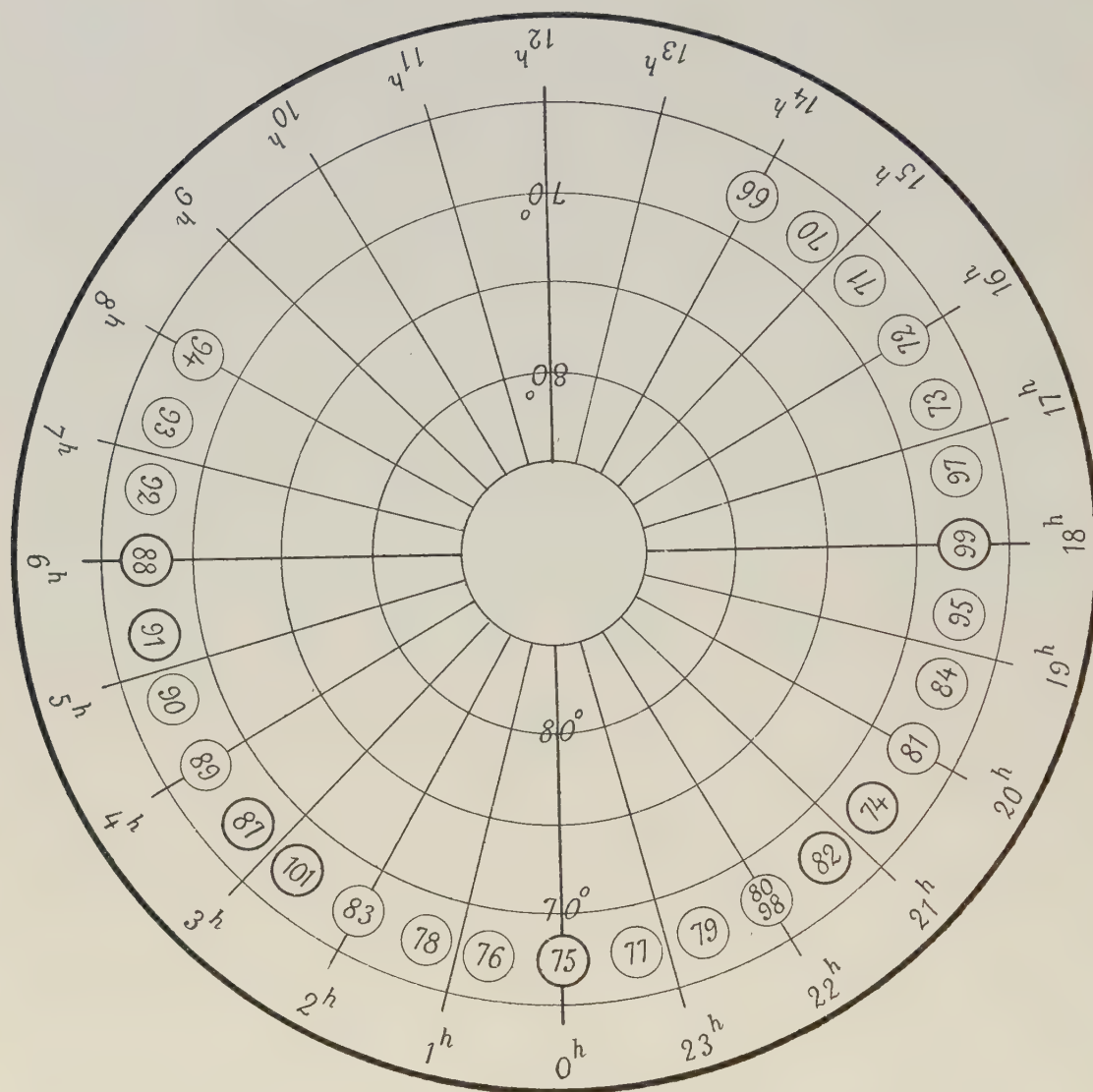


Fig. 1. The position of the program plates in the Greenwich polar zone.

As mentioned above, all spectra in the zone have been broadened by means of a micrometric displacement of the plate between successive exposures. The time has as a rule been 4 minutes for each exposure, and 14 such exposures have been taken to form the complete spectral image. The total exposure time of a widened image has thus been 56 minutes. In addition to such an exposure one with grating placed in front of the prism has also been taken on every program plate. The exposure time for the grating images was kept the same as for the other ones.

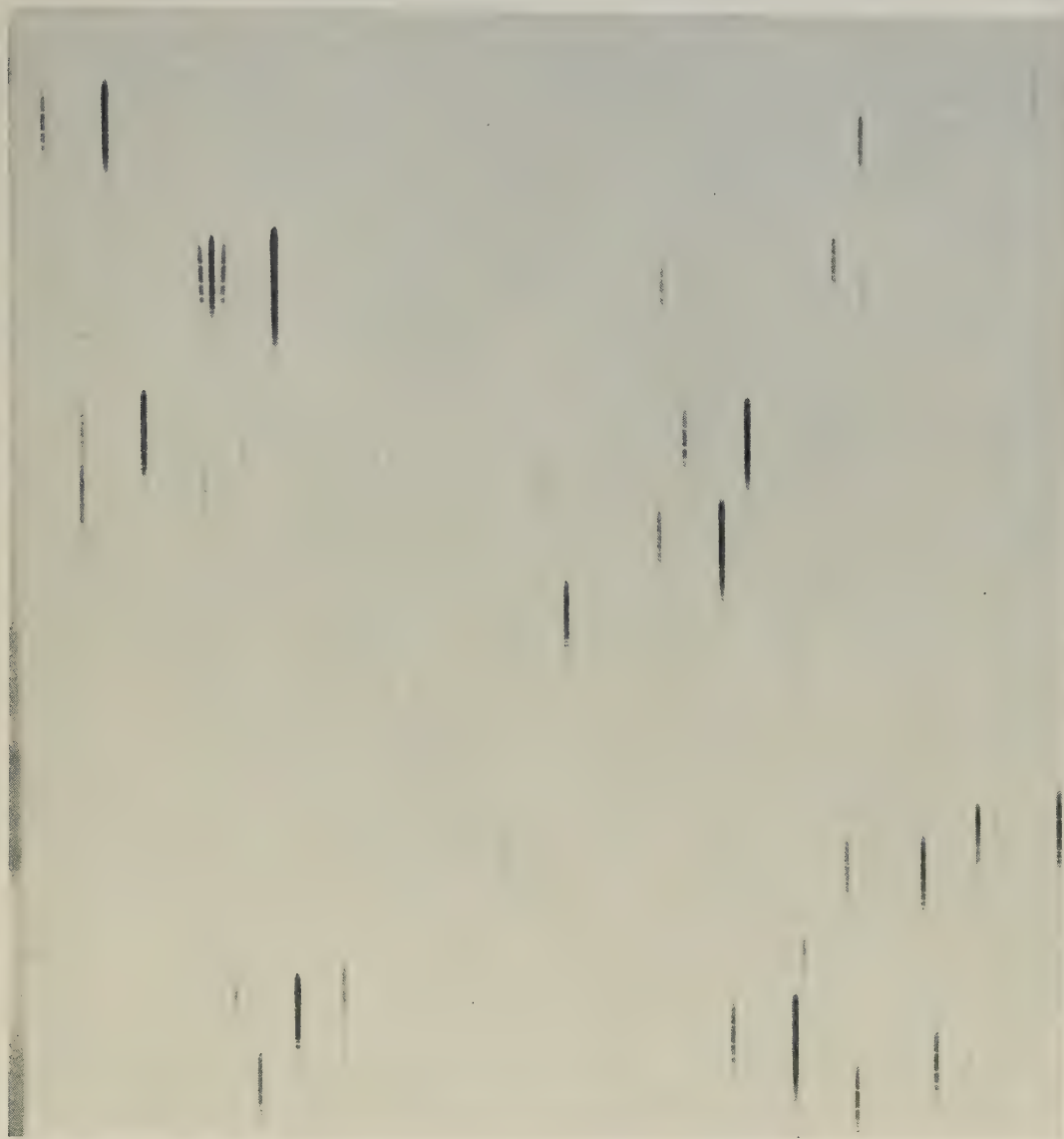


Fig. 2. A part of plate No. 87, 3 times enlarged.

The aim of taking grating images was to determine the plate characteristics according to HERTZSPRUNG's »prism-crossed-by-grating» method.¹ At the same time measurable images could be obtained also for the brighter stars and often two images of such stars could be measured on one and the same plate. Fig. 2 gives an example of how the plates look. It is a part of plate No. 87 enlarged 3 times.

¹ E. HERTZSPRUNG, Photographisch-spektralphotometrischer Vergleich zwischen Altair und Nova Aquilae 3 in der Nähe ihrer maximalen Helligkeit, Astr. Nachr. 207, p. 75, 1918.

Table I. (Zone Plates.)

Plate No.	Date	Exp. without grating	Exp. with grating	Right asc. of centre	Decl. of centre	Observers
66	1927 March 24	$12^h 31^m - 13^h 41^m$; 11×5^m	$11^h 18^m - 12^h 28^m$; 11×5^m	$14^h 0^m$	$67^\circ 30'$	Ld.
70	April 27	$13 10 - 14 19$; 14×4	$14 25 - 15 34$; 14×4	$14 40$	»	Ld., Ön.
71	28	$13 50 - 14 56$; 14×4	$15 5 - 15 57$; 11×4	$15 20$	»	Ld., Ön.
72	May 1	$13 24 - 14 31$; 14×4	$14 44 - 15 51$; 14×4	$16 0$	»	Ld.
73	2	$13 32 - 14 50$; 16×4	$15 4 - 15 54$; 11×4	$16 40$	»	Ld., Ön.
74	Aug. 30	$20 39 - 21 52$; 15×4	$22 1 - 23 6$; 14×4	$20 40$	»	Ld., Ön.
75	31	$21 8 - 22 12$; 14×4	$22 22 - 23 26$; 14×4	$0 0$	»	Ld., Ön.
76	Sept. 2	$20 58 - 22 5$; 14×4	$22 10 - 23 17$; 14×4	$0 40$	»	Ld., Ön.
77	4	$20 44 - 21 49$; 14×4	$21 54 - 22 57$; 14×4	$23 20$	»	Ld., Ön.
78	20	$21 20 - 22 24$; 14×4	$22 31 - 23 36$; 14×4	$1 20$	»	Ld., Ön.
79	21	$21 28 - 22 31$; 14×4	$22 38 - 23 41$; 14×4	$22 40$	»	Ld., Ön.
80	22	$20 29 - 21 32$; 14×4	$21 37 - 22 3$; 6×4	$22 0$	»	Ld., Ön.
81	29	$21 4 - 22 7$; 14×4	$22 15 - 23 20$; 14×4	$20 0$	»	Sn., Ön.
82	Oct. 3	$22 36 - 23 38$; 14×4	$23 45 - 0 52$; 14×4	$21 20$	»	Ld., Ön.
83	18	$22 56 - 0 1$; 14×4	$23 16 - 1 15$; 14×4	$2 0$	»	Ld., Sn.
84	Nov. 1	$21 15 - 22 20$; 14×4	$22 33 - 23 46$; 14×4	$19 20$	»	Ön.
87	1928 Feb. 10	$5 0 - 6 5$; 14×4	$6 13 - 7 23$; 14×4	$3 20$	»	Ön.
88	13	$8 23 - 9 35$; 14×4	$10 16 - 11 25$; 13×4	$6 0$	»	Ön.
89	20	$7 33 - 8 40$; 14×4	$8 59 - 10 13$; 14×4	$4 0$	»	Ön.
90	23	$5 24 - 6 41$; 14×4	$7 53 - 9 5$; 14×4	$4 40$	»	Ön.
91	March 10	$6 45 - 7 55$; 14×4	$8 23 - 9 30$; 14×4	$5 20$	»	Ön.
92	14	$8 20 - 9 27$; 14×4	$9 35 - 10 40$; 14×4	$6 40$	»	Ön.
93	21	$8 21 - 9 33$; 14×4	$9 41 - 10 49$; 14×4	$7 20$	»	Ön.
94	April 13	$11 36 - 12 50$; 14×4	$13 7 - 14 25$; 14×4	$8 0$	»	Ön.
95	Sept. 9	$22 15 - 23 27$; 14×4	$23 51 - 1 0$; 14×4	$18 40$	»	Ön.
97	Nov. 7	$21 26 - 22 34$; 14×4	$22 49 - 23 58$; 14×4	$17 20$	»	Ön.
98	Dec. 6	$2 4 - 3 14$; 14×4	$3 26 - 4 37$; 14×4	$22 0$	»	Ön.
99	31	$0 52 - 2 5$; 14×4		$18 0$	»	Ön.
101	1929 Feb. 1	$5 33 - 6 48$; 14×4	$7 23 - 8 21$; 12×4	$2 40$	»	Ön.
102	Sept. 12	$20 28 - 21 3$; 14×2		$18 0$	»	Ön.
		$21 18 - 21 54$; 14×2		$0 0$	»	
103	Oct. 31	$21 51 - 22 30$; 14×2		$21 0$	»	Ön.
		$22 44 - 23 19$; 14×2		$0 0$	»	
104	Nov. 1	$0 23 - 1 5$; 14×2		$3 0$	»	Ön.
		$2 1 - 2 39$; 14×2		$0 0$	»	
		$3 4 - 3 45$; 14×2		$5 40$	»	
105	Nov. 1		$4 26 - 4 48$; 14×1	$3 39$	$24 10$	Ön.
		$5 59 - 6 21$; 14×1		$0 0$	$67 30$	

Ld. = Lindblad; Sn. = Schalén; Ön. = Öhman.

In addition to the ordinary zone plates, some plates have been taken in order to compare the sensitiveness for different wavelengths of plates situated far from one another. Though the zone plates form a connected series, it is necessary to fix some plates and compare them directly with a standard plate. Plate No. 75 has thus been selected as the standard and this field has been photographed on the same plate as one or two other fields in the zone, the altitude of observation always being the same. In this way secondary standard plates have been obtained for determinations of colour. In Fig. 1 these standard plates have been denoted by bold line circles. The additional zone plates has been given a shorter exposure time than the ordinary plates. One plate has also been taken in order to connect the Pleiades with the standard No. 75.

The observational data concerning the zone plates are collected in Table I. In the 3rd and 4th column is given the sidereal time at the beginning of the first and the end of the last exposure. In addition, the number of exposures forming the image and the exposure time is given. The plates have as far as possible been taken near to the meridian but in some cases the exposures had to be made at rather great hour angles. Plate 66 has been displaced 0.020 mm. between successive exposures but for all the others the displacement have been 0.015 mm.

In Table II I have given the data of some other plates taken for different purposes. Three plates were taken with the Lund Observatory prism in order to

Table II. (Miscellaneous Plates.)

Plate No.	Date	Sidereal Time	Object	Remarks
D 4	1927 Oct. 22	0 ^h 22 ^m — 1 ^h 16 ^m	Pleiades	Lund prism. Eyepiece scale.
D 5	Nov. 30	2 26 — 3 17	»	» »
D 8	1928 March 8	6 34 — 7 26	»	» »
D 10	April 25	12 25 — 13 50	α Urs. Min.; β Urs. Maj.	Varying density. Diurnal motion.
D 11	26	12 45 — 1 30	β Urs. Maj.	Varying focus. Diurnal motion.
D 18	1930 March 16	7 10 — 8 39	Bright F stars	Grating crossed by prism.
D 19	23	11 18 — 14 50	»	»

study line intensities from spectra in a greater dispersion. These spectra were broadened by means of successive displacement of the guiding star in an eyepiece scale. The density curves were derived from old measurements of the Pleiades.¹ Two plates were taken for special study of the influence of varying density and focus on line intensity measurements. In this case the plate characteristics have been obtained partly from images taken with different sector diaphragms¹ and partly from grating images (α Urs. Min.). The spectra were broadened by the

¹ Compare: Y. ÖHMAN, Medd. etc. Upsala, No. 33, 1927.

diurnal motion, the instrument being kept fixed. Finally two plates were taken of bright F stars with well known luminosities. The spectra were broadened by micrometric displacement of the plate. Besides these a number of test plates of different kinds have been taken.

The plates used in the present work are Ilford Special Rapid Plates, patent plate. All the ordinary zone plates had the sensitiveness H. & D. 270, the plates 102, 103 and 104 were extra sensitive H. & D. 400. The plates have been developed in Rodinal ($1/20$) for about 7 minutes at a temperature of 18° . The plates have proved to be very suitable for spectrophotometric work.

In table III some data concerning the plate characteristics are collected. The first columns give plate number and emulsion. Then I have given the difference in stellar magnitude between the photographic densities 0.499 and 0.903, measured with the Schilt photometer. This quantity may be regarded typical for the straight line portion of the H.D. curve. Dividing 1.009 by this quantity, the gradation is obtained. A great difference in magnitude is thus equivalent with a flat curve, a small difference with a steep one. These typical numbers have been given for three different wavelengths. Then I have given the corresponding differences between the densities 0.101 and 0.499. These numbers may thus in connection with the above ones characterize the curvature of the lower part of the H.D. curves. In column 9, as a limiting magnitude, is given Greenwich photographic magnitude corresponding to the density 0.350 at the wavelength λ 4161 and valid for A type stars in the centre of the plate. Fainter stars have generally not been measured for purposes of determining line intensities. In the last column I have finally given a correction in order to standardize the relative situation of the characteristic curves for λ 4415 and λ 3912, the difference in magnitude between these two wavelengths being used as a colour-equivalent of the stars. As the different plates may show different relations between sensitivity¹ and wavelength and as the plates are taken at varying zenith distances, it was necessary to reduce the colour measurements to a common standard. As was mentioned above, the plate No. 75 was selected standard. The corrections have been determined in two different ways; the details will be found in Chapter V. The methods employed for the determination of the characteristic curves are described in the next chapter.

An inspection of Table III shows that plates of the same emulsion as a rule have similar characteristic curves, though considerable variations sometimes may occur. The emulsion 6154 C shows an abnormally strong gradation. When comparing the different wavelengths, we find a very obvious relation between the shape of the characteristic curves and the wavelength. The mean values at the end of the table show that *the gradation is decreasing with decreasing wavelength for the spectral region in question*. This result is in accordance with most investiga-

¹ By sensitivity is here meant the photographic density produced by a certain amount of energy. The term sensitivity is also often identified with the gradation, that is the increase in density with a certain increase in intensity logarithm.

Table III.

Plate No.	Ilford Patent Plate Emulsion No.	Difference in magnitude between densities 0.499 and 0.903			Difference in magnitude between densities 0.101 and 0.499			Limiting magnitude λ 4161	Corr. to colour equivalent
		λ 4415	λ 4150	λ 3912	λ 4415	λ 4150	λ 3912		
66	8052 D	0.75	0.73	0.78	1.30	1.33	1.47	9.0	+0.01
70	»	0.69	0.70	0.75	1.23	1.28	1.31	9.1	+0.06
71	»	0.70	0.70	0.74	1.23	1.29	1.28	9.2	+0.06
72	»	0.74	0.74	0.74	1.33	1.35	1.39	9.3	+0.05
73	»	0.72	0.73	0.79	1.47	1.34	1.43	9.2	+0.03
74	6085 E	0.66	0.68	0.71	1.27	1.33	1.39	9.3	+0.01
75	»	0.66	0.68	0.73	1.22	1.28	1.37	9.0	± 0.00
76	»	0.62	0.64	0.62	1.28	1.36	1.41	9.2	-0.01
77	»	0.66	0.69	0.73	1.23	1.32	1.31	9.0	+0.01
78	»	0.67	0.71	0.71	1.24	1.25	1.34	9.1	+0.02
79	»	0.66	0.71	0.74	1.25	1.30	1.36	9.2	+0.03
80	»	0.63	0.67	0.68	1.25	1.29	1.32	9.2	+0.06
81	»	0.64	0.66	0.71	1.26	1.30	1.39	9.3	± 0.00
82	»	0.68	0.72	0.74	1.27	1.32	1.36	9.1	-0.02
83	»	0.68	0.72	0.76	1.22	1.28	1.37	9.1	+0.02
84	»	0.71	0.72	0.76	1.34	1.42	1.41	9.1	+0.04
87	6103 E	0.73	0.73	0.79	1.30	1.33	1.48	9.1	+0.01
88	»	0.84	0.84	0.88	1.36	1.42	1.50	9.2	-0.01
89	»	0.80	0.78	0.79	1.36	1.37	1.44	9.3	-0.04
90	»	0.79	0.80	0.82	1.41	1.49	1.46	9.3	+0.01
91	»	0.82	0.84	0.82	1.42	1.50	1.53	9.4	+0.01
92	»	0.83	0.87	0.85	1.41	1.50	1.54	9.4	± 0.00
93	»	0.71	0.72	0.76	1.25	1.31	1.32	9.3	-0.02
94	»	0.78	0.81	0.84	1.34	1.38	1.45	9.2	-0.07
95	6129 D	0.73	0.78	0.84	1.15	1.21	1.29	8.4	-0.07
97	6154 C	0.61	0.64	0.68	1.09	1.11	1.17	8.6	+0.05
98	»	0.56	0.59	0.61	1.06	1.14	1.17	8.6	+0.07
99	»	0.59	—	0.63	1.11	—	1.16	8.8	+0.01
101	»	0.56	0.60	0.62	1.14	1.16	1.17	8.6	+0.06
Mean from 28 plates		0.701	0.721	0.750	1.274	1.324	1.373		
Mean gradation		1.44	1.40	1.35					

tions on this subject.¹ The limiting magnitude in the ninth column is remarkably constant, only the plates 95—101 show a marked deviation as to sensitivity. Because of the insensitivity of these plates, the zone is at present not so complete as was originally planned.

CHAPTER III.

The Measurements and their Reduction.

1. *The Schilt photometer.* The photographic plates have been measured with the Schilt photometer of the Uppsala Observatory. As the construction of this photometer has been described in detail by SCHILT² and as to its essential features also by myself³, I will confine myself here to some summarizing remarks.

With the Schilt photometer, densities are measured by means of a thermopile and galvanometer. A 6 Volt automobile lamp illuminates a diaphragm, the light first passing through a short focus condensing lens and a red filter. By an objective the diaphragm is then projected 25 times diminished on the photographic plate, after which the pencil of light is led into the thermopile by means of a second objective. The thermocurrent is measured with a critically damped galvanometer, the readings being made with telescope and scale. In the reading telescope a part of the photographic plate in the neighbourhood of the analyzing beam comes also into view, and by this arrangement the settings are very easily performed.

The plate is carried by two movable frames and all parts of a 16×16 cm. plate may thus be analyzed. As the motion of the frames was found to be rather too rapid to allow accurate settings the cylindrical axes directing the motions were made movable and equipped with slow motion screws and springs. When using the slow motion, the frames have at first to be fixed to the axes by means of clamping screws. The arrangement was found to constitute a considerable improvement in the instrument.

As the analyzing beam is strongly converging into the photographic plate, the latter has to be placed at exactly the same distance from the first objective as the image of the diaphragm. To that end the thermopile is temporarily exchanged for an eyepiece and the objectives are adjusted until the diaphragm shows no parallax relative to the plate grains. At the same time a sharp image is obtained on the

¹ See for instance:

F. E. ROSS, The physics of the developed photographic image., Monographs on the theory of photography, from the Research Laboratory of the Eastman Kodak Company, No. 5, 1924.

H. B. DORGELO, Die photographische Spektralphotometrie, Physikal. Zeitschr. 26, p. 756, 1925.

² J. SCHILT, Description of the new thermopile-microphotometer of the Leiden observatory, Bull. Astr. Inst. Netherlands, Vol. II, p. 135, 1924.

³ Y. ÖHMAN, Medd. etc. Upsala. No. 33, 1927.

thermopile. If the plate is quite parallel to the plane defined by the motions of the frames, every point of the plate will come at the same distances from the objectives. If, however, the plate is not perfectly plane, the distances will vary and new adjustments have to be made. In the present work this adjustment were very often controlled and if marked variations appeared, new adjustments were always made.

A fundamental feature of the Schilt photometer is that the thermopile has a nearly constant surface sensitivity. At the same time the image of the diaphragm can be given an almost homogeneous illumination by adjusting the condensing lens in front of the diaphragm. In order to control these two points, the galvanometer deflection for different circular diaphragms were measured. The deflection was shown to be satisfactorily proportional to the diaphragm areas, at least for moderate size of the diaphragms. This fact is of importance in measuring line intensities.

The density of a photographic images is generally defined as:

$$D = \log_{10} \frac{J_1}{J_2} \quad (\text{III: 1})$$

where J_1 is the intensity of an incident beam of light in the photometer and J_2 the intensity of the same beam when transmitted through the silver deposit of the image. The density thus defined shows the well known relation to light intensity logarithm usually called the characteristic curve of a plate. For moderate and not too strong intensities the relation is almost linear, for faint densities the line shows the well known curvature.

With the Schilt photometer real densities may of course be determined, the deflection of the galvanometer being proportional to the intensity of the analyzing beam of light. For practical purposes it is, however, convenient to use the galvanometer deflection itself instead of the density calculated according to (III: 1). In the employment of this method it is necessary, however, to standardize the deflection of clear plate. In the present investigation the measurements were always made relative to the fog (clear plate) in the neighbourhood of the image. The measurements were thus performed in the following manner. A suitable zero point (27.00 cm.) was selected on the galvanometer scale and by moving the scale this point could be made to coincide with the reading telescope's crosshair when the analyzing beam of light was shut off. As the zero point of the galvanometer and thermopile remained remarkably steady, frequent adjustment was unnecessary. The beam of light was then allowed to enter the thermopile and the brightness of the 6 Volt lamp was altered by means of a continuous regulating rheostat in order to fix the mean galvanometer deflection for the fog to certain suitable scale reading (3.00 cm.). When finally setting an image in the analyzing beam, the scale reading itself gave a definite measure of the density of the photographic image. At the same time

an eventual error depending on a variation in the density of the fog was to a large extent automatically eliminated. We will for a moment direct our attention to the latter fact.

2. *The influence of fog.* It is generally not possible to get a plate quite free from fog, as the night sky is often a little illuminated and a plate as a rule also shows developed silver grains when not exposed. But if the fog is perfectly uniform and the plate characteristic is derived from the plate images themselves we have no trouble from such a general fog. If, on the other hand, the fog shows considerable variations within the plate there may appear faults, and an image situated on a dark background will show a stronger density than an image situated on a background free from fog. If the fog could be exactly measured we could of course apply a correction analogous to that proposed by SCHWARZSCHILD.¹ When using a photo- or thermoelectric microphotometer it is not possible, however, to measure the fog quite exactly, because variations in the thickness of the plate and the emulsion may produce variations in the galvanometer deflections, impossible to distinguish from real variations in the density of the fog. In the present work I have therefore employed a method which automatically reduces the influence of the fog, though it cannot compensate completely for the influence. The density of an image is simply measured relative to the density of the fog in the neighbourhood of the image by varying the intensity of the 6 Volt lamp to give the fog the standard reading 3.00. If the density (D) were related to acting intensity (i) according to $D \sim i$, the measurements would in this case be perfectly freed from influence of the fog. For faint densities, where the fog may be dangerous, the relation between D and i may, it is true, be regarded as linear, but the line does not start from the origin, since the plate requires a certain amount of radiating energy before the straight line portion is reached. We must therefore always expect a small error to remain. In order to investigate the magnitude of this error, I have made some test intensity scales, by photographing a light source (lamp enclosed in a box with round paper window) at various distances from the plate. Half the plate was given a general and uniform fog. When plotting the density measurements in a diagram against intensity, I found that the curve for the part of the plate free from fog and the curve for the part given a general faint exposure were exactly parallel with respect to the intensity axis, the intensity of the fog being simply added to the scale. The densities of both curves were expressed in relation to clear plate. When forming the relative densities between the scale images in the additionally exposed part of the plate and the fog of this part, it was found that the corresponding curve was situated very nearly half way between the other curves and could be regarded parallel to these. The test plates have thus shown that when measuring relative densities as proposed above we reduce the influence of the fog intensity by about one half. In the following Table IV I

¹ K. SCHWARZSCHILD, Über die Schleierkorrektion bei der Halbgittermethode zur Bestimmung photographischer Sterngrößen, Astr. Nachr. 193, p. 81, 1912.

have given some values showing the magnitude of errors introduced by a fog. In the first column is given the difference between the magnitude of the fog and the true stellar magnitude of an image. In the second column I have calculated the errors ε' introduced by the fog in the case of relative densities. The calculation is based on the result found from the test scale plates, that the intensity of the fog in this case enters with only half its amount. The last column finally shows the errors ε'' introduced when measuring absolute densities.

Table IV.

m	ε'	ε''
$0^m.0$	-0.44	-0.75
1.0	-0.21	-0.37
2.0	-0.08	-0.16
3.0	-0.03	-0.08
4.0	-0.01	-0.03
5.0	-0.00	-0.01

When applying these results to the present spectrophotometric investigation we must remember that only the variations in the fog have to be considered, the characteristic curves being deduced for the average fog of the plate. These variations are generally rather small, and as the faint images have been excluded, the faults introduced by the fog in the present investigation probably do not as a rule exceed the value corresponding to $m = 3.0$, that is, 0.03 stellar magnitudes. Moreover we may remember that the present work consists mainly of relative measurements in short spectra and the influence of the fog is thus generally reduced to the accidental plate errors.

3. *The standardization of the plates.* As already mentioned the photometric principle of the present investigation is that of grating-crossed-by-prism. The grating used is the same as already described in my paper of 1927. The grating, which was used earlier by LINDBLAD for determinations of effective wave-lengths, has the grating constant 1.26 mm. The distance on the plate between spectra of the first order is thus about 1 mm. The breadth of the threads of this grating is very nearly equal to the free space intervals between the threads.

The chief point of the grating method is that every bright star besides a central image also gives fainter first order spectra at both sides, the intensity of these lateral images always being a certain fractional part of the intensity of the central image. By comparing the densities of the first order spectra with the density of the central image, for different stars, we are thus able to derive the characteristic curve of the plate without introducing special calibration scales.

The problem of deriving the characteristic curve from the densities of the grating images is equivalent to solving a functional equation of the type:

$$\varphi(m+k) = \chi[\varphi(m)]. \quad (\text{III: } 2)$$

In this equation $\varphi(m)$ is the relation looked for between photographic density and stellar magnitude. k is the magnitude constant of the grating, that is, the difference in magnitude between the first order spectra and the central image. The function $\chi(D)$ finally expresses the relation between the density of first order spectra and the density of the central image. This relation may be empirically determined by measuring a number of stars of different brightness and plotting the two quantities against each other.

In the present work the function $\varphi(m)$ has been determined by a graphical method without any assumptions as to the mathematical form of the function $\chi(D)$. As already mentioned the density has not been calculated explicitly but the standardized galvanometer readings have been used themselves. Fig. 3 shows such characteristic curves for plate No. 70 derived for the three wavelengths $\lambda 4415$, $\lambda 4150$ and $\lambda 3912 \text{ \AA}$. To the left in the figure the relations between galvanometer reading of the central image Rc (ordinate) and the corresponding reading for the first order spectra Rs (upper abscissa) are shown. The reading 27.0, corresponding to complete blackness, is common for both kind of images. From these curves the relations between galvanometer reading and stellar magnitude (ordinarily $-m = 2.5 \log i$) have been constructed remembering that a reading Rs always corresponds to an image k magnitudes fainter than the corresponding Rc reading. I have thus started at the Rc reading 19.4 (corresponding to the density 0.50) and given this point a magnitude value 3.0 (lower abscissa). The galvanometer reading for the abscissa $3.0 - k$ is then obtained from the curves to the left, as the corresponding Rs value. The reading for $3.0 + k$ is on the other hand obtained as the Rc value corresponding to $Rs = 19.4$. From the new points obtained in this way the same procedure is repeated and in this way five points on the characteristic curve may as a rule be obtained. To control the curve constructed from these points, some new starting points have been selected and the different curves have been adjusted until they show a common shape.

In earlier work I have determined the magnitude constant k of the grating to be $0^m.94$ and this value has been preliminarily adopted for the construction of all plate characteristics. As, however, the material used for the previous determination of k was rather poor, I have in the present investigation made a more rigorous determination.

According to the theory of gratings there exist certain relations in intensity between the grating images and a corresponding image taken without grating. If d denotes the breadth of the threads and l the free space between them, the in-

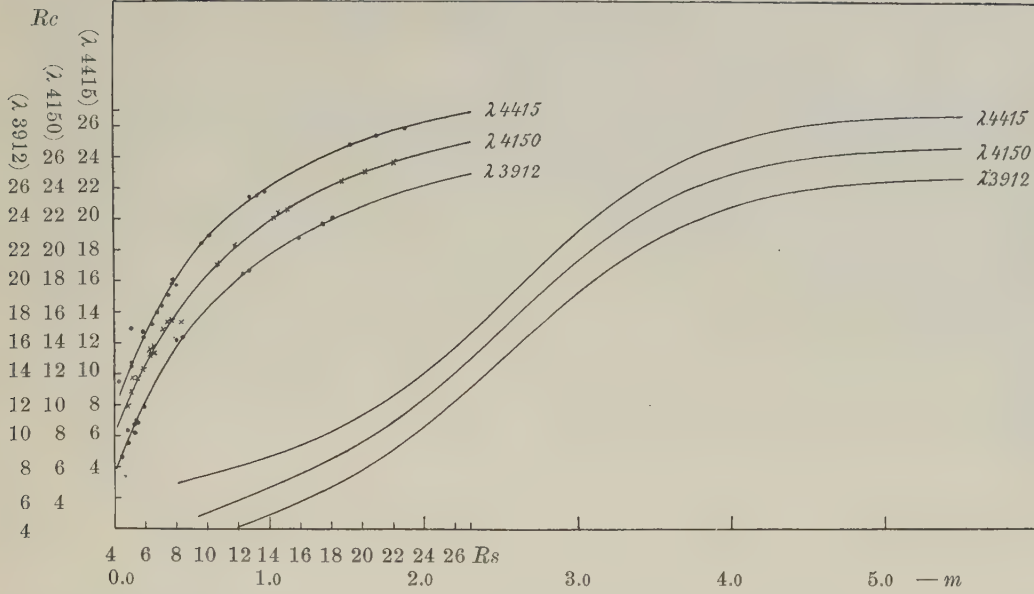


Fig. 3. Characteristic curves of plate No. 70. The curves to the left give the relationship between the galvanometer readings of central image (Rc) and first order spectra (Rs). From these the curves to the right, between galvanometer reading and stellar magnitude, have been obtained.

tensity of the central image, taking the intensity of the image without grating as unity is

$$I_c = \frac{l^2}{(l + d)^2}. \quad (\text{III: } 3)$$

The intensity of the spectra of the n th order is expressed in the same unit:

$$I_n = \left(\frac{\sin \frac{l}{d+l} n\pi}{n\pi} \right)^2. \quad (\text{III: } 4)$$

From formula (III:4) is clear that I_1 does not change its value appreciably for small deviations from $d=l$. As the grating used in the present investigations fulfils this condition very closely I have followed HERTZSPRUNG and determined the magnitude constant by adopting the theoretical value 2.486 for the difference in magnitude between the spectra of the first order and the image taken without grating. Suppose we have measured a plate taken both with and without grating and that we have found the mean magnitude difference Δ between the central image taken with grating and the image taken without grating. If the plate characteristics have been derived by means of the preliminary grating magnitude constant g , we then find the true constant G by means of the formula

$$G = 2.486 \frac{g}{A + g}. \quad (\text{III: } 5)$$

The zone plates made good material for a determination according to this method. Ten plates taken under very steady weather conditions and showing uniform spectra have been selected and measured for this purpose. If the two exposures were taken on different zenith distances, a correction for varying transmission has been applied, using the transmission coefficients for Washington determined by ABBOTT and FOWLE.¹ The determinations were made for the three wavelengths $\lambda 4415$, $\lambda 4150$ and $\lambda 3912$. In accordance with the results found at Greenwich², no clear variation of the grating magnitude constant with wavelength could be established. The ten plates gave the following mean value for the grating magnitude constant:

$$G = 0.899 \pm 0.001 \quad (\text{m.e.}).$$

The circumstance that photographic magnitudes have been earlier determined for the stars at Greenwich gave a method for controlling the above value of the constant. For the B 8—A 2 stars of 11 plates I have thus derived photographic magnitudes from the density measurements at the wavelengths $\lambda 4270$ and $\lambda 4161$, taking into account a centre correction for the instrument determined by PETERSSON.³ These magnitudes were plotted against the Greenwich photographic magnitudes reduced to the International scale by applying the corrections Harvard Annals 71, p. 224 and Harvard Bull. 711. From the slope of the straight line connecting the points, the grating magnitude constant has been calculated. In this way I have from eleven plates derived the value:

$$G = 0.895 \pm 0.010 \quad (\text{m.e.}).$$

The agreement between the two determinations is thus very good and this argues in favour of both Hertzsprung's method for determining the magnitude constant, and the correctness of the International photographic magnitude scale. The grating constant adopted for the present work is:

$$G = 0.90.$$

As the plate characteristics were previously derived by means of the constant 0.94, all measurements have been reduced by 4.3 % in order to give true magnitude differences. This correction should also be applied to my paper of 1927.

¹ Annals of the Astrophys Obs. of the Smithsonian Inst. Vol. II, p. 113, 1908.

² W. M. H. GREAVES, C. DAVIDSON and E. MARTIN, Monthly Notices 87, p. 356, 1927.

³ J. H. PETERSSON, Effective wave-lengths of faint Milky Way stars in Aquila. Arkiv för matem., astr. o. fys., 19 A, No. 3, 1925.

CHAPTER IV.

The Wide-Slit Method of Measuring Line Absorption.

1. *Theoretical basis.* The line intensities given in this work have been measured by means of a Schilt photometer with a wide rectangular diaphragm, as previously mentioned. With such a diaphragm the analyzing beam will enclose most of the line contour even in the case of the very strong hydrogen lines of A type stars. This method of measuring line intensities is thus contrary to the ordinary spectrophotometric methods where the spectra are taken in rather strong dispersion and the lines are analyzed by means of a self registering, microphotometer of high resolving power. My method may at a hasty glance appear somewhat dangerous and without any physical meaning. In my previous paper of 1927, however, it was found that the quantity obtained in this way is a good measure of the total absorption within spectral lines, and the accuracy of the measurements is indeed remarkably high. As the settings are very easily made and as also faint stars may be investigated, the method seems in several cases to be of great value. Though the method has been described earlier, the main points as to the meaning of the measurements may be summed up here.

By means of the Schilt photometer the density of a photographic image is measured with thermopile and galvanometer. But only in the case of a fairly uniform blackness of the image can we get a true value of its density, since the analyzing beam of this photometer cuts out a comparatively great area. On the other hand if the density varies from point to point within the analyzing beam, the galvanometer reading will give a mean value of the area investigated.

The density D may be calculated according to (III: 1) from the galvanometer deflection d by means of the formula

$$D = \log_{10} \frac{d_0}{d}, \quad (\text{IV: 1})$$

d_0 denoting the galvanometer deflection of the fog. As mentioned before, d_0 is kept constant.

Let us consider a photographic image of a stellar spectrum. The density D varies from point to point within this image and we assume we may express the dependence between density and position in spectrum by means of a certain function. For purposes of simplification we write this relation:

$$d = f(x). \quad (\text{IV: 2})$$

We must remember that this formula does not give the relationship we would obtain by passing through the spectrum with the Schilt photometer. Instead, it

may be regarded as giving the tracing we would obtain from a self registering microphotometer of high resolving power giving the same deflections for uniform densities as the Schilt photometer.

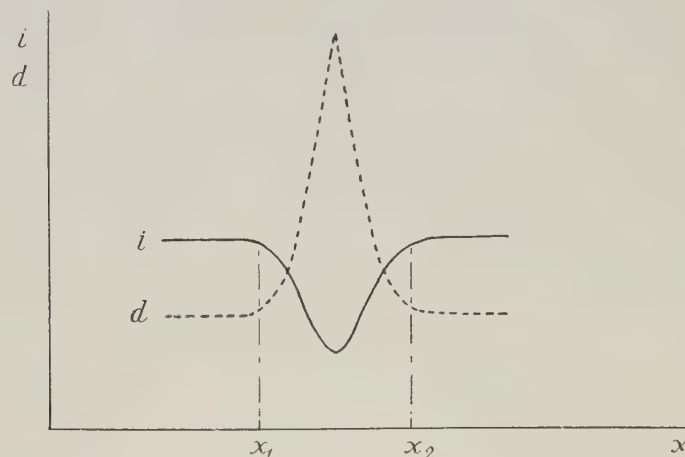


Fig. 4. Line contour. The curve i gives the apparent intensity distribution in spectrum. d is the fictitious galvanometer deflection corresponding to successive densities within the line contour.

Suppose we now examine a certain absorption line in the spectral image (Fig. 4). We want to know: When setting the analyzing beam of the Schilt photometer on this line, what quantity will be given by the scale reading? As the galvanometer deflection varies almost linearly with the cross-sectional area of the analyzing beam (compare page 19) it is obvious that the galvanometer deflection when setting on a line may be expressed by:

$$\bar{d} = \frac{1}{a} \int_{x_1}^{x_2} f(x) dx. \quad (\text{IV: 3})$$

Here x_1 and x_2 denote the limits of the spectral region analyzed and $a = x_2 - x_1$, the width of the analyzing beam of light.

We wish to convert the expression (IV: 3) into one for light intensity. We assume that the characteristic curve of the plate is given by the relations:

$$d = \chi(i), \quad \text{or} \quad i = \psi(d). \quad (\text{IV: 4})$$

The intensity value J corresponding to the deflection d is thus according to the characteristic curve equal to:

$$J = \psi \left(\frac{1}{a} \int_{x_1}^{x_2} f(x) dx \right). \quad (\text{IV: 5})$$

We assume that the apparent intensity distribution within the spectral image (Fig. 4) may be expressed by

$$i = \varphi(x). \quad (\text{IV: 6})$$

Introducing this function in (IV: 5) by means of (IV: 2) and (IV: 4) we get finally:

$$J = \psi \left(\frac{1}{a} \int_{x_1}^{x_2} \chi(\varphi(x)) dx \right). \quad (\text{IV: 7})$$

Thus this is the quantity given by the measurement. It is seen from this expression that the value J depends upon the shape of the characteristic curve of the plate. This fact may seem to imperil the success of the method, as the measure of line absorption must be a function of the density of the image. As will be seen from the following, the value J will, however, be independent of the density in the straight line portion of the ordinary plate characteristic and here the measurements have thus a quite special meaning.

The straight line portion of the characteristic curve of a plate may be written

$$D = D_0 + \gamma \log_{10} i \quad (\text{IV: 8})$$

where γ is the slope or gradation of the characteristic and D_0 a certain constant. Replacing the density by the galvanometer deflection d according to (IV: 1) we get

$$d = i^{-\gamma} d_0 10^{-D_0} = \chi(i) \quad (\text{IV: 9})$$

$$i = d^{-\frac{1}{\gamma}} (d_0 10^{-D_0})^{\frac{1}{\gamma}} = \psi(d).$$

By introducing these functions in (IV: 7) we get the following expression:

$$J = \frac{1}{\left[\frac{1}{a} \int_{x_1}^{x_2} \frac{dx}{[\varphi(x)]^\gamma} \right]^{\frac{1}{\gamma}}}. \quad (\text{IV: 10})$$

This is the quantity measured in the straight line portion of the characteristic curve. If the gradation equals unity we see that J becomes the *harmonic mean intensity* of the spectral region. This is easy to understand if one remembers that the galvanometer deflection is greatest for small densities, that is, for small acting intensities.

From formula (IV: 10) it is obvious that our line measures have a good theoretical basis. It is true that the gradation enters into the expression and that different plates for that reason may give somewhat different J values, but the

variations introduced in this way are negligible, since the expression (VI: 10) varies very slowly with γ . This is apparent in the following table (Table V). Assuming the line contour to be an isosceles triangle with an altitude or central depth of 1.19 stellar magnitudes, I have calculated the line intensity as a function of the gradation γ according to (IV: 10). The line absorption is defined as the difference between the magnitude, corresponding to the deflection when setting on the line, and the magnitude of the continuous background. If the plate material is homogenous, the variations may obviously be kept within narrow limits. As is clear from Table III, the plates used in this work have, as a rule, about the same gradation. Some exceptions occur, however, and probably the faults introduced in this way may in some cases amount to 0.03 magnitudes. But it has not been found necessary to apply corrections according to varying gradation, and it was impossible to derive definite corrections from the material at hand.

Table V.

Gradation γ	Line absorption
1.0	0. ^m ₅₄₂
1.2	0.553
1.4	0.564
1.6	0.575
1.8	0.586

From the above is evident that the quantity obtained when analyzing an absorption line by means of a Schilt photometer is very nearly the harmonic mean intensity of the apparent line contour.

In this connection the question may arise: Is it possible to measure the arithmetic mean intensity of a line contour by a similar method? The arithmetic mean intensity would from some points of view be preferable. It gives a true expression for the total line absorption and at the same time the measurements will be almost free from faults connected with unsharpness of the spectrum. From formula (IV: 7) is obvious that the arithmetic mean will be measured if the relationship between intensity and density of the image is given by:

$$D = D_0 - \log_{10} i. \quad (\text{IV: 11})$$

Such a relationship may of course not be fulfilled for an ordinary plate. But when measuring a positive contract plate the conditions are altered. Suppose the negative plate has the gradation γ_1 , and the positive plate the gradation γ_2 . The relationship between density in the positive plate and intensity in the original spectral image is then easily found to be of the form:

$$D = D_0 - \gamma_1 \gamma_2 \log_{10} i. \quad (\text{IV: 12})$$

This equation is seen to be identical with (IV: 11) if $\gamma_1 \gamma_2$ equals unity. With positive plates it seems thus possible to measure the true total line absorption with the wide slit method. The result is the same as if we could directly project the stellar radiation on the thermopile. In order to test this method some positive spectra have been measured. The measurements have shown a close similarity to the »harmonic» line intensities obtained from negative plates. The »harmonic» line intensities as a rule has been found somewhat greater than the »arithmetic», and indeed this is exactly what is to be expected. When comparing positive plates of different blackness, however, it has been found that the line absorption increases with the density of the interstellar fog. Plates with very dark fog thus sometimes show the »arithmetic» line absorption equal to the »harmonic» one. This systematic error seems to be due to an EBERHARD development effect. This error is one reason for not using positive plates. Another weak point of this method is that it introduces new plate errors and often only a small part of the characteristic curve can be used.

We return to the expression (IV: 10) valid for negative plates. The fact that this expression has the character of a harmonic mean may seem dangerous if we want to measure the total absorption in spectral lines. But we must remember that (IV: 10) is not valid in the case of small densities. If there exists a narrow part in a line of very faint intensity it will be reduced considerably in weight when forming the harmonic mean. Moreover the line contours are always smoothed out a little in the small dispersion spectra I used. Indeed the measured quantity does not deviate much from the arithmetic mean and my line intensity may thus be considered as *a good measure of total absorption*. The measures may vary a little for different apparatus but not for the same one if normally exposed images are used.

The difference in magnitude for settings on line and continuous background has been employed to define the line intensity. The photometer-diaphragm used for the present investigation is rectangular and cuts out 23 Å at H γ , 19 Å at H δ and 16 Å at the K line. The different intervals are due to the prismatic scale. These intervals may appear too narrow when studying the total absorption and of course the outer wings of the strongest lines are not completely embraced by the analysing beam. But it has not been possible to use a wider diaphragm on account of the small distance between K and H ζ , as this region was measured for the purpose of determining colour. Different diaphragms could perhaps have been used for different spectral regions, but this would have been inconvenient. As the diaphragms used includes the main part even of very strong lines, it was adopted as the most convenient one.

The lines measured in the present work are H γ , H δ and K. H γ has been measured relative to the background defined by the wavelengths λ 4415 and λ 4270,

$H\delta$ relative to $\lambda 4161$ and $\lambda 4055$ and the K-line relative to a single wavelength, $\lambda 3912$.

2. *Empirical tests.* Though the wide-slit method of measuring line intensities seems to be founded according to the above on a sound basis, it is necessary to test this question by means of empirical data. It may appear that the theoretical result that only the straight line portion of the characteristic curve gives harmonic means, will demand that only plates showing perfectly linear characteristics must be used. But as only comparatively small magnitude differences are measured and as a faintly varying gradation does not produce appreciable errors, this condition need not be strictly fulfilled in order to get good results. Nevertheless in the region of faint densities, where the characteristic curve shows a considerable curvature, a systematic decrease in the line absorption will present itself. This fact comes to view in Fig. 5, which shows the dependence between line intensity $H\delta$ and density of the continuous background of the spectral image D for the star β Urs. Maj. The measurements are obtained from test plate $D 10$.

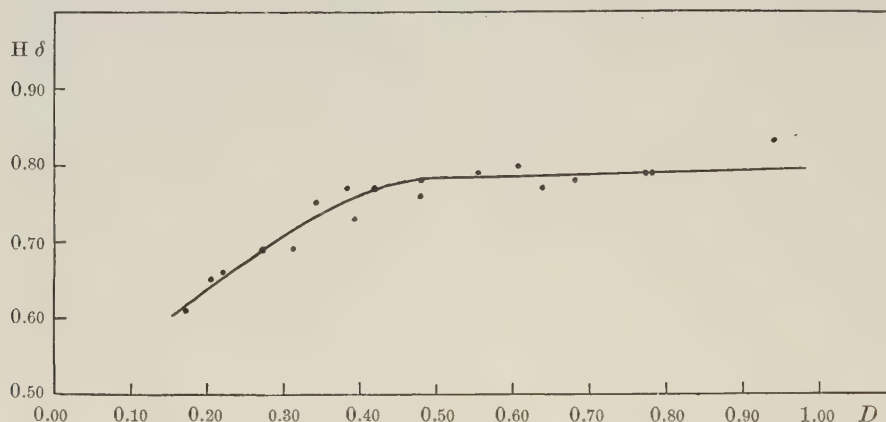


Fig. 5. The dependence between line intensity and density of the continuous background.

From the figure is obvious that the line intensity is independent of the density for moderate densities, but from the density 0.40 the line intensity decreases with decreasing density. Similar curves are obtained for the other lines, and also other test plates have shown the same relation. The point far to the right indicates an increase in line intensity for strong densities. This effect has also been found from other plates but as a rule only for still stronger densities. It seems to be due to the EBERHARD effect. By studying such relationship for different line intensities, a system of correction curves could of course be deduced. I have, however, found it better to avoid images so dense that a correction has to be applied.

3. *The influence of different dispersion.* We have thus found that our line intensities may be regarded as free from systematic errors depending on the dens-

ity of the image, if a suitable density interval is used. We will now see to what extent the line intensities are characteristic of the apparatus used. If the quantity measured had been the harmonic mean of the true contour, this quantity would of course appear whatever instrument had been used. The spectrum, however, is not perfectly pure and this circumstance must introduce an »instrumental equation». For purposes of studying this equation and in order to get further data as to the

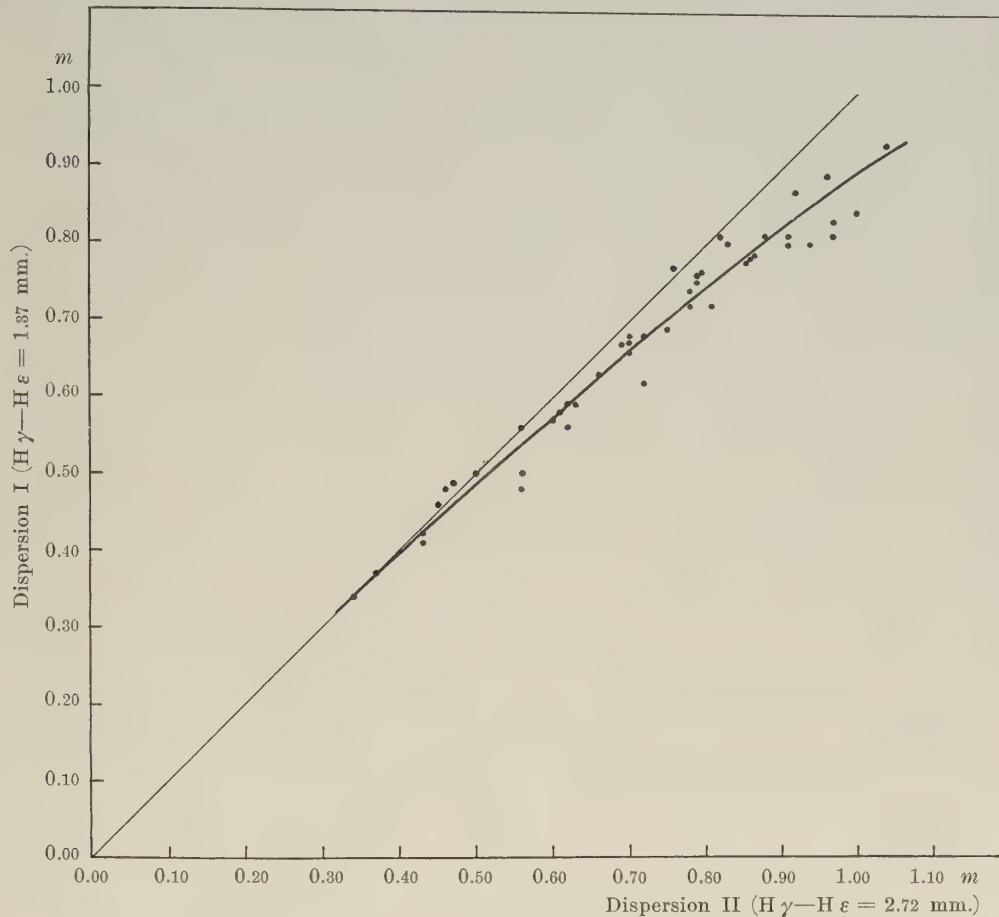


Fig. 6. Comparison between line intensities obtained from two different dispersions.

usefulness of the method I have compared line intensities derived from spectra taken in two different dispersions. The $9^{\circ}.7$ Upsala Observatory prism which has been used for the program work gives in conjunction with tube No. 1 of the Zeiss Heyde astrograph a dispersion of 1.37 mm. between $H\gamma$ and $H\delta$. The $10^{\circ}.0$ Lund Observatory prism combined with tube No. 2 gives on the other hand a distance of 2.72 mm. between the same lines. The second combination thus gives very nearly twice the dispersion of the former between these lines. Moreover, the

shape of the prismatic scale for the two prisms does not deviate appreciably within the interval. In order to compare spectra taken in the two dispersions, three plates were taken of the Pleiades in the greater dispersion (D 4, D 5, D 8) and compared with plates taken in the ordinary dispersion (plates used in my earlier work as well as different test plates). The short spectra have been measured with the ordinary rectangular diaphragm (breadth = 1.77 mm.), the longer spectra, on the other hand, with a 3.51 mm. rectangular diaphragm. The two diaphragms thus correspond to almost the same wavelength interval in the two different dispersions.

Fig. 6 shows the comparison between the two kinds of line intensities. As a rule a point in this diagram is the mean of at least three independent determinations. In this figure I have collected together both measures of $H\gamma$ and $H\delta$, the diagrams of the different lines showing no systematic difference. From the figure is obvious that the two dispersions give identical results for small line intensities but for stronger lines the greater dispersion gives stronger line absorption. The deviation is, however, astonishingly small, remembering that it is due to the difference in sharpness between the two dispersions plus the variation in the surface sensitivity of the thermopile. The result points out that the »instrumental equation» when measuring hydrogen line intensities is rather small, and as the scattering of the points is slight, measures obtained from different instruments seem to be easily converted into each other.

4. *Sources of error.* From the above I think we are entitled to regard the line intensities as founded on a safe basis. It remains, however, to investigate the extent to which the measurements may be affected by accidental and systematic errors. Apart from causes depending on the imperfection of the method treated above, such errors may depend on the following factors:

- a) Bad definition of the spectral image caused by poor focus, the situation of the image on the plate and unsteady weather conditions.
- b) Longitudinal stripes in the spectrum and inclination of the spectral lines.
- c) Accidental plate errors and varying fog in different parts of the plate.
- d) EBERHARD development effects.
- e) Effects of stray light.
- f) Faults in the characteristic curve employed for the reductions.
- g) Imperfect adjustment of the plate and the analyzing beam of the photometer.
- h) Fluctuations in the brightness of the photometer lamp and the zero point of the thermopile-galvanometer system and accidental variations of the galvanometer deflection caused by induced electric currents and different kinds of mechanical vibrations.
- i) Faults in the settings and scale readings when measuring the plates.

Of the above causes contributing to errors in the line intensities we will at first pay attention to the effect of poor focus (a). In order to test the influence of varying focus a series of images of the star β Urs. Maj. has been taken in dif-

ferent focal distances (Plate D 11).

Fig. 7 gives the line intensity as function of focal setting for different hydrogen lines. The curves show that it is important to work with a good focus. A fault in the focusing of 0.2 mm. does, however, not introduce greater errors than 0.02 stellar magnitudes and the focus may be regarded kept within these limits. It is interesting to note the different situation of the maxima for the different spectral lines. This is due to the secondary spectrum or focal curve of the objective, and indeed the secondary spectrum may be derived from these very curves. This has been done in Fig. 8 and the curve obtained in this way coincides almost perfectly with the one earlier determined by LINDBLAD¹. The lines $H\gamma$ and $H\delta$ are in good focus at the same time. As to the K -line, however, it has always been photographed a little out of focus. For this reason the K -line is more sensitive to variations in focus. In connection with this, however, it should be mentioned that the influence of focus is much smaller on faint lines than on strong ones. The fainter lines are completely embraced by the analyzing beam and as the harmonic mean does not deviate much from the arithmetic, the influence of focusing is considerably diminished. This

question has been settled by measuring plate D 11 with a wider diaphragm.

As to the other causes I will confine myself to some short remarks. No faults arising from the varying situation of the spectra in the plate field (a) have been

¹ Compare page 11.

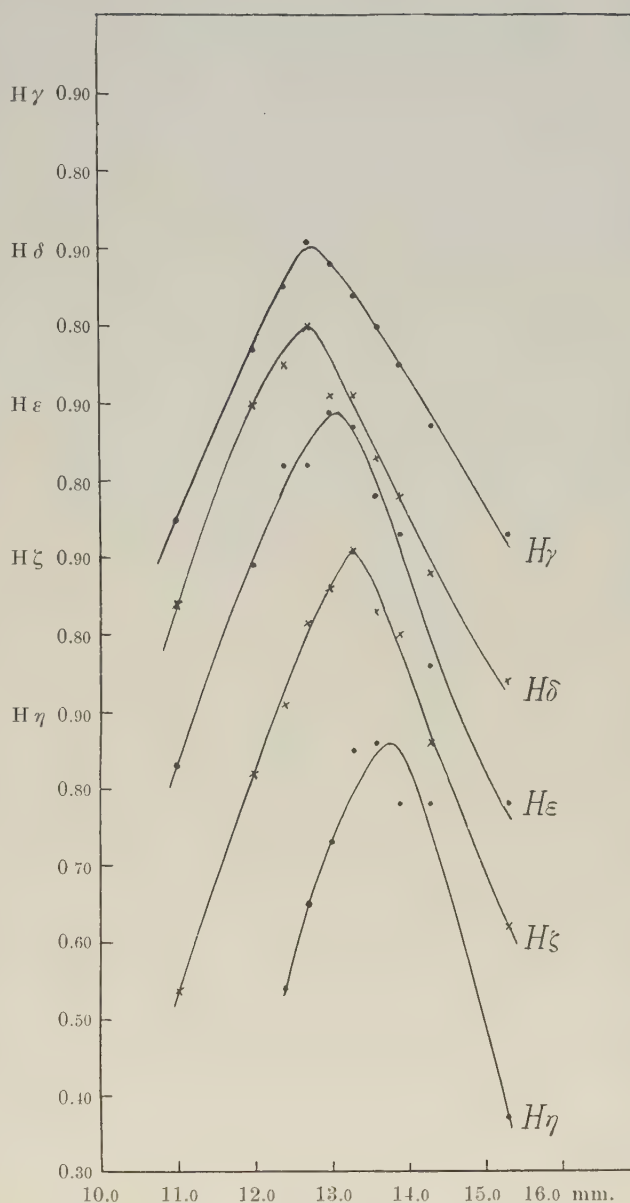


Fig. 7. Line intensity as a function of focal setting.

found; the definition of the images is indeed very good over almost the whole plate field. This fact has been settled by comparing images common to adjacent zone plates.

The longitudinal stripes (b) occurring in some spectra are too slight to introduce appreciable errors. If the spectral lines were not been perfectly perpendicular to the longitudinal direction the plate was adjusted until the spectral lines have become parallel to the rectangular diaphragm. The slight shortening of the scale appearing by this process is too small to need consideration. The fact that some spectra show a faint inclination of the lines has been due partly to a small error in the adjustment of the astrograph and partly to an imperfect adjustment of the prism relative to the direction of broadening.

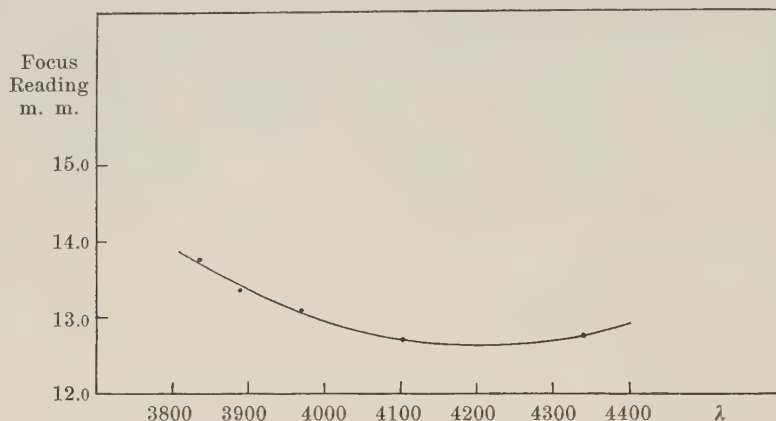


Fig. 8. Focal curve for objective I of the Zeiss-Heyde astrograph of Upsala Observatory.

The accidental plate errors (c) are as a rule small and as to the influence of fog it is of no importance as has already been shown in Chapter III.

The EBERHARD development effect (d) is only dangerous for strong densities and such images have been avoided

Effects of stray light (e) have not been found. It seems inappreciable, according to the investigation of SHAPLEY and MISS PAYNE¹.

The faults in the characteristic curves (f) are faint and the faults arising in the measurement of the plates in the photometer (g, hand i) are very small. As a rule they do not exceed 0.02 magnitudes. In the present work every image has been measured twice.

5. *Mean errors.* To get an idea of the accuracy of the wide-slit method of measuring line intensities, I have determined the mean error in the determination of line intensity from one image. The determination is based on stars in the Greenwich zone appearing on two different plates. Suppose $\mathcal{A}$ is the difference between

¹ CECILIA H. PAYNE and H. SHAPLEY, On the Distribution of Intensity in Stellar Absorption Lines, Harvard Reprint 28, 1926.

the two different measurements and that n stars have been investigated, then the mean error $\bar{\varepsilon}$ in the determination from one image is obtained from the formula:

$$\bar{\varepsilon} = \sqrt{\frac{\sum \mathcal{A}^2}{2n}}. \quad (\text{IV:13}).$$

The followin table (Table VI) gives the result of this determination for different spectral lines. The hydrogen lines have been divided into two groups according to line intensity:

Table VI.

Line	$\bar{\varepsilon}$ (stellar magnitudes)	n
H γ < 0.50	0.038	134
H γ $\geq$ 0.50	0.045	175
H δ < 0.50	0.037	121
H δ $\geq$ 0.50	0.048	186
K all	0.052	229

No stars have been excluded in this determination. As is seen from the table, the errors are quite small. The stronger lines show somewhat greater errors than the smaller ones, as we might have expected. The K -line shows the greatest error but this may be due to a greater focus effect and to the fact that the continuous background in this case is defined by a single wavelength.

Table VI may be regarded as constituting definite proof that the wide-slit method is very useful in the measurement of line absorption.

6. *Comparison with Miss WILLIAMS' measurements.* In addition to the above, we may compare my line intensities and the total absorption measured by Miss WILLIAMS¹ from microphotometer tracings. The stars common in our lists are unfortunately too few to allow a satisfactory comparison. As, however, both Miss WILLIAMS and myself² have compared the line intensities with the Upsala luminosity classes based on visual estimates, an indirect comparison is possible. This comparison for the line H γ is given in Fig. 9: It is based on 26 stars measured by Miss WILLIAMS and 55 stars measured by me. As is seen from the figure, the points are situated very close to a straight line, indicating that my line intensities on the whole are good measures of total absorption. It appears that the two quantities may be converted into each other by means of this relation without the introduction of serious errors. The unit of total absorption used by Miss WILLIAMS

¹ EMMA T. R. WILLIAMS, A Spectrophotometric Study of A stars, Harvard Circular 348, 1929.

² Compare Fig. 15 and 16.

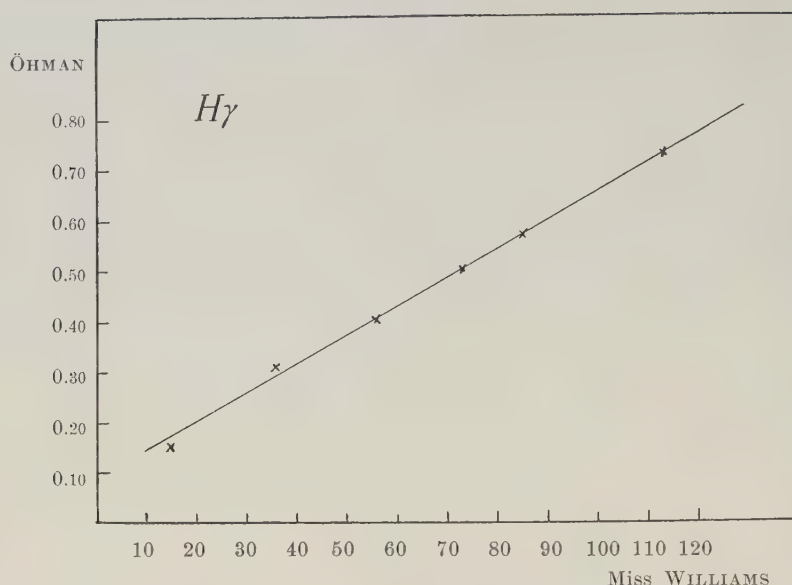


Fig. 9. Comparison between Miss WILLIAMS' total line absorption and ÖHMAN's line intensity.

is »the width (expressed in frequency units) of a hypothetical section of continuous spectrum in the neighbourhood of the line containing an amount of energy equivalent to that blocked off by the absorption line».

CHAPTER V.

The Temperature-Equivalent.

1. *General considerations.* In connection with the line intensity work it was desirable also to determine a temperature-equivalent for the stars. As the spectra have been taken on ordinary plates, the spectral region available for determinations of temperature is rather limited. When determining gradient temperatures of stars it has always been found necessary to select a spectral region where the continuous spectrum is very nearly like a Planck curve in shape. As, however, the stellar spectra often show a depression of the radiation curve in the violet¹, it did not seem to me that real temperature determinations were possible from my spectra. Nevertheless a determination of a spectrophotometric gradient may in such a case give a good measure of temperature because the depression in the continuous curve, probably caused by line and band absorption, seems often to be primarily a func-

¹ Compare A. BRILL, Spektralphotometrische Untersuchungen, Astr. Nachr. Band 219, p. 353, 1923.

tion of temperature. For that reason I have measured the magnitude difference between the wavelengths $\lambda 3912$ and $\lambda 4415$ (C) and used this quantity as a measure of temperature. As the present work aims at a study of the dependence between hydrogen line intensity and temperature, it is of importance that the wavelengths mentioned above should be uninfluenced by the wings of the hydrogen lines. As to $\lambda 3912$, the nearness of $H\zeta$ may seem dangerous. Stars showing very wide hydrogen lines might be expected to be measured systematically redder than stars with sharp lines. When comparing my diagram between hydrogen line intensity and colour with the one obtained from Miss WILLIAMS'¹ measurements, no such effect could be detected. The influence of $H\zeta$ seems thus to be very small. It was desirable to measure a point below $H\epsilon$ in order to get a sufficiently wide interval in wavelength.

When determining a spectrophotometric gradient like the one in question, a number of different factors have to be taken into consideration. The gradient directly measured from a spectral image is only an apparent gradient, the true energy curve being altered partly by constant instrumental factors (absorption in the lenses and prism and prismatic scale) and partly by the varying factors connected with sensitivity of plates and atmospheric transmission. Only the factors giving rise to variations in the gradient are of importance in this connection, and the chief problem is to reduce all measurements to a common system.

As already mentioned in Chapter II, the zone plate No. 75 has been selected as the standard and all measurements have been reduced to the system defined by the stars on this plate. This reduction has been possible both by comparing stars on adjacent overlapping plates and by direct comparison of certain regions in the zone (secondary standards) with the field 75, and finally also by means of measurements of the K -line. As will be shown in Fig. 30 there exists a pronounced correlation between the intensity of the K -line and colour equivalent C . This relation has been deduced separately for all plates and compared with the relation obtained from plate 75 and the secondary standards. We have thus two methods for determining the corrections necessary to reduce all plates to the same standard. The corrections given in the last column of Table III are weighted means of determination according to these methods. For plates situated between two standards I have given the determinations, obtained from the two different sides, weights inversely proportional the number of comparisons to be made before reaching the standards. For plates with a secondary standard on only one side (Fig. 1) a greater weight has been given to the determination from the K -line, as the standard in this case has not been transmitted from plate to plate but the adopted value for one plate based on the two methods has been transmitted to the adjacent plate, and so on. The two methods have been given somewhat different weights according to the correlation obtained for the K -line and the accuracy in the comparison of adjacent plates. As is shown in Table III the corrections are as a rule very small.

¹ Loc. cit. on page 35.

2. *Mean error.* A colour-equivalent of the kind studied here is easily measured with the SCHILT photometer. The errors appearing in the determinations are due chiefly to plate error, faults in the characteristic curves, and imperfect correction for transmission and sensitivity of plates. A comparison of stars common to adjacent plates has given the following mean error in the determination of the colour-equivalent from one image calculated according to formula (IV:13):

$$\bar{\varepsilon} = 0^m.052 \quad (n = 308).$$

The error is small in view of the difficulties involved in determinations of spectrophotometric gradients.

3. *Comparison with other colour measures.* To get a clear view of the quality of the temperature equivalent used in this work, we have to make a comparison between the C values determined here and determinations of temperatures or colours made by other methods. In my earlier work¹ I gave a comparison between HERTZSPRUNG's colour indices and my colour-equivalents for the Pleiades which showed a pronounced correlation between these two quantities. The material at hand for an analogous comparison from the present list of stars is very scanty.

Accurate colour or temperature determinations are available for only twelve bright stars in the zone. In Table VII I have made a compilation of different determinations of these stars performed by BRILL (calculated)², YÜ³, Miss WILLIAMS⁴, BOTTLINGER⁵, GERASIMOVIC⁶ and HERTZSPRUNG⁷ (compilation). All these determinations have been reduced to the scale defined by BRILL (loc. cit.), which is based on KING's colour indices. These reductions were made possible by the tables given by BRILL and the comparisons made by the different authorities. A reduction curve had to be constructed by the writer only in the case of YÜ's determination.

The different determinations have been given different weight according to the following scheme:

BRILL 300, YÜ 200, WILLIAMS 200, BOTTLINGER 100 times the number of observations, GERASIMOVIC 100 and HERTZSPRUNG the numerical weight given in his compilation. The weight given to HERTZSPRUNG's values may appear small but these

¹ Medd. etc. Upsala No. 33, 1927.

² A. BRILL, Temperaturen und scheinbare Halbmesser von 134 Sternen. Astr. Nachr. 223, p. 105, 1924.

³ CH'ING-SUNG YÜ, Lick Bull. 375, 1926.

⁴ EMMA T. R. WILLIAMS, Harvard Circular, 348, 1929.

⁵ K. F. BOTTLINGER, Lichtelektrische Farbenindizes von 459 Sternen, Veröff. der Universitätssternwarte zu Berlin-Babelsberg. III, Heft. 4, 1923.

⁶ B. P. GERASIMOVIC, Harvard Circular 339, 1929.

⁷ E. HERTZSPRUNG, Mean Colour Equivalents and Hypothetical Angular Semi-Diameters of 734 Stars Brighter than the Fifth Magnitude and within 95° of the North Pole. Annalen Van De Sterrewacht Te Leiden XIV:1, 1922.

determinations seem to be affected by a magnitude equation (compare Miss WILLIAMS' paper).

Table VII gives Boss number of the stars, spectral type, the quantity C measured by me, with the number of images within brackets, and the different determinations of $\frac{c_2}{T}$ reduced to BRILL's scale. The number of observations is given after BOTTLINGER's values and the numerical weight after HERTZSPUNG's. In the last column I have given the adopted mean value and the sum of the weights.

Table VII.

Boss	Spectrum	C	$\frac{c_2}{T}$ (BRILL)	$\frac{c_2}{T}$ (YÜ)	$\frac{c_2}{T}$ (WILLIAMS)	$\frac{c_2}{T}$ (BOTTLINGER)	$\frac{c_2}{T}$ (GERASIMOVIC)	$\frac{c_2}{T}$ (HERTZSPUNG)	$\frac{c_2}{T}$ (Mean)
550	A 5 p	0.37 (4)			1.59			1.68 (53)	1.61 (253)
741	B 3 p	0.08 (2)					0.24	0.62 (51)	0.38 (157)
1139	B 0	0.30 (2)				1.06 (2)	1.01	1.38 (69)	1.11 (369)
1556	A 0	0.25 (4)				1.22 (1)		0.72 (48)	1.06 (148)
1744	B 5	0.14 (2)				1.09 (1)			1.09 (100)
4213	B 8 p	0.14 (3)			1.26	1.19 (1)		0.72 (69)	1.14 (369)
4322	F 5	0.64 (5)						1.95 (69)	1.95 (69)
4368	B 5	0.11 (4)	0.89	0.96	0.96	1.00 (2)			0.95 (900)
4483	F 5	0.58 (3)						2.25 (69)	2.25 (69)
4948	A 2	0.20 (2)						1.06 (69)	1.06 (69)
5532	B 3	0.04 (4)				0.63 (6)			0.63 (600)
6108	A 0	0.11 (4)				1.24 (1)			1.24 (100)

As is seen from the table there exists an evident correlation between my C values and the compiled $\frac{c_2}{T}$ values. This is more apparent in Fig. 10, where the different quantities are plotted against each other. The greatest points have a weight of more than 300 and are based on at least four spectra measured by me. Those of intermediate size have a weight of at least 150 and the smallest are stars with a weight less than 150. The material, however, is scanty for the construction of a line which may convert the two quantities into each other. In order to complete the material I have studied mean colour-equivalents for different spectral types. These mean values may be compared with corresponding mean values given by

BRILL.¹ The crosses in Fig. 10 are obtained from this comparison. To proceed in this way is dangerous, however, from several points of view. BRILL's values are based on bright stars but mine on stars down to the ninth magnitude and the different selections may introduce serious errors. A number of yellowish A stars of small luminosity are thus present in my list, and in the case of early B stars, my colours may be affected by space reddening. For that reason I have used only the F stars when constructing the curve giving the relation between C and $\frac{c_2}{T}$. As is seen

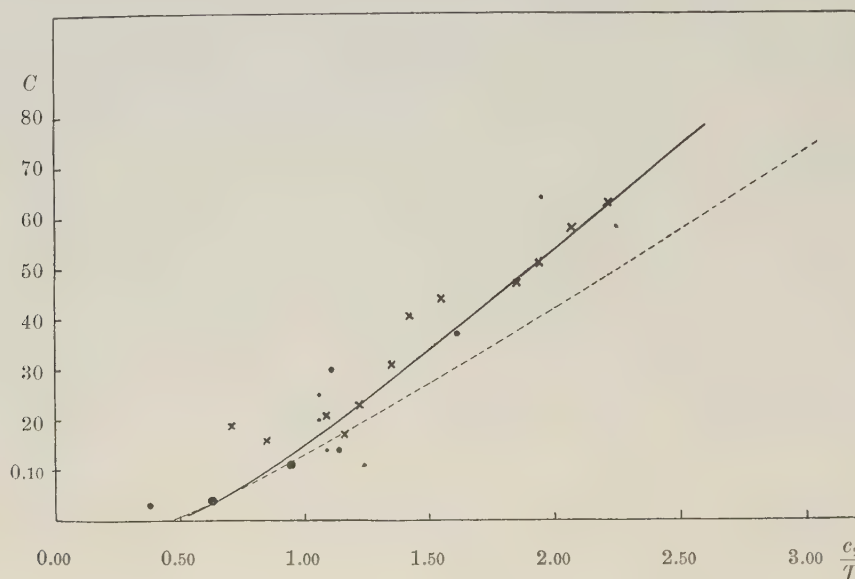


Fig. 10. Comparison between the colour-equivalent C and $\frac{c_2}{T}$ values deduced by other authors. The points give direct comparisons. The different sizes of the points denote different weights. The crosses are obtained from mean values for successive Harvard types. The dotted curve corresponds to a true Planckian gradient.

from the figure, the F stars (four upper crosses) are situated very close to the curve giving the relation. The points obtained from Table VII are also satisfactorily placed.

¹ It must be remarked here that my values refer to Harvard types but BRILL's to the types given by BOTTLINGER and HARPER and YOUNG. But the systematical errors which may appear in this way are very small.

Later on BRILL has modified his temperatures a little. (Zeitschr. für Phys. 52, p. 779, 1929.) The new temperatures which are somewhat higher agree better with those recently given by SAMPSON (Monthly Notices 90, p. 652, 1930) with the exception of the B stars. On the other hand the agreement with the scale given by RUSSELL, DUGAN, and STEWART (Astronomy, II, p. 753, 1927) is less satisfactory in the case of BRILL's scale of 1929. As BRILL's scale of 1924 proceeds very nearly in the middle between those given by SAMPSON and RUSSELL, DUGAN, STEWART, I have adopted the scale of 1924 as it stands.

In Table VIII I have collected the mean colour-equivalents for different spectral types. The numbers in parentheses denote the numbers of stars used in determining the C value. I have also given the $\frac{c_2}{T}$ values which corresponds to my C values according to the empirical curve in Fig. 10.

Table VIII.

Spectral type	C	$\frac{c_2}{T}$ (derived from C)	$\frac{c_2}{T}$ (BRILL 1924)
B 0—B 2	0.19 (7)	1.11	0.71
B 3—B 5	0.16 (20)	1.02	0.85
B 8	0.21 (30)	1.17	1.09
B 9	0.17 (48)	1.05	1.16
A 0	0.23 (227)	1.22	1.22
A 2	0.31 (120)	1.43	1.35
A 3	0.41 (46)	1.67	1.42
A 5	0.44 (47)	1.76	1.55
F 0	0.47 (78)	1.83	1.85
F 2	0.51 (50)	1.93	1.94
F 5	0.58 (73)	2.10	2.07
F 8	0.63 (49)	2.23	2.21

In Fig. 11 the two kinds of $\frac{c_2}{T}$ values are given as functions of the spectral type. The dotted line is BRILL's curve and the other one joins my points. The remarkable deviation of the latter from the former may seem to point out that the quantity C is not a pure temperature-gradient. The deviation of the B-stars is, however, probably due to space reddening. (Compare Chapter VII.) As to the deviation for the A stars, it has been pointed out above that the different selection is a factor to be taken into account. Moreover, we must remember that BRILL's curve is based on much less material than mine and his curve is smoothed out.

The characteristic break in my curve between A 3—A 5 and F 0 (compare Chapter VI) may indeed be seen in most comparisons between spectral type and colour, for instance those by KING¹, SEARES², BOTTLINGER³, ÖPIK⁴ and KRIEGER⁵.

¹ E. S. KING, Combined out-of-focus results from several instruments, Harvard Annals 76, p. 124, 1916.

² F. H. SEARES, Relation of colour to intrinsic luminosity in stars of the same spectral type. Proc. Nat. Acad. of Sciences, V, p. 235, 1919.

³ K. F. BOTTLINGER, Loc. cit., p. 38, Tafel I.

⁴ E. ÖPIK, Determination of colour-equivalents of stars according to Tikhoff's method. Publ. l'Observatoire Astronomique etc. de Tartu, XXVI, 3, pp. 33—34, 1925.

⁵ C. J. KRIEGER, A determination of magnitudes, spectral types and colour indices in the Sentum Cloud with a statistical discussion, Lick Bull. 416, p. 104.

6—30736. Nova Acta Reg. Soc. Sc. Ups., Ser. 4, Vol. VII. No 3. Impr. 27/10 1930.

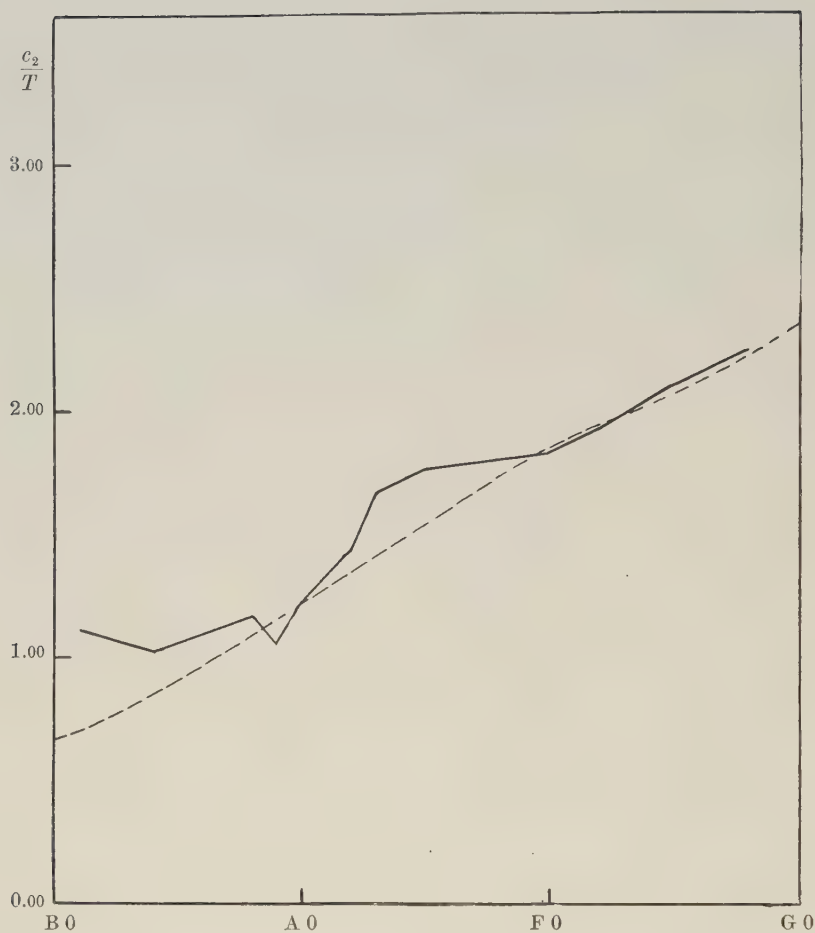


Fig. 11. $\frac{c_2}{T}$ as a function of spectral type. The fully drawn curve is obtained from the C values, the dotted one is the relation given by BRILL.

The same phenomenon comes to view in the effective wavelengths.¹ This effect is surely to a great extent due to a real temperature effect, but it is probably also connected with the deviation of the radiation curve from a Planckian curve, because the effect is more pronounced for some colour equivalents than for others.²

4. *Deviation from black body curve.* Is of interest in this connection to in-

¹ H. J. GRAMATZKI, Die visuellen effektiven Wellenlängen der helleren Fixsterne. Astr. Nachr. 222, p. 150, 1924.

R. CHERUBIM, Die Methode der effektiven Wellenlängen und ihre Anwendung auf den offenen Sternhaufen M 34. Veröff. Univ. Sternwarte, Göttingen, Heft 9, 1929.

² This question is further discussed in Chapter VIII.

investigate how near the quantity C comes to a gradient in the Planckian curve, or in other words what temperatures may come directly from this quantity.

The apparent intensity distribution in a stellar spectrum may be written

$$J = C_1 \varphi(\lambda) \chi(\lambda) \lambda^{-5} / \left(e^{\frac{c_2}{\lambda T}} - 1 \right). \quad (\text{V: 1})$$

Here C_1 is a certain constant, $\varphi(\lambda)$ a function depending on the atmospheric extinction, the absorption in the lenses and the prism, the prismatic scale and finally the sensitivity of plates. $\chi(\lambda)$ is a function giving the deviation of the true intensity distribution from a Planckian curve. When determining stellar temperatures, C_1 may be eliminated by measuring a gradient and $\varphi(\lambda)$ can be made to disappear by determining the gradient relative to a known standard, for instance a star with well known temperature, observed at the same altitude as the star to be measured. The function $\chi(\lambda)$ makes the determination difficult. If this function varies from star to star the results will be affected by errors. But if on the other hand $\chi(\lambda)$ is the same for all stars, including the standard, it will be eliminated at the same time as $\varphi(\lambda)$. As we noticed above, $\chi(\lambda)$ is of importance in the violet region of stellar spectra, where we have a remarkable depression of the radiation curve. But within the types B, A and F the depression is not so very strong and it does not as a rule vary much from type to type.¹ Thus we have reason to expect that the quantity C may give temperatures not far from the truth.

By logarithmic differentiation of (V: 1) we derive the following expression:

$$C = C_0 + 0.316 \left[\frac{c_2}{T} \cdot \frac{1}{1 - e^{-\frac{c_2}{\lambda T}}} - \frac{c_2}{T_0} \cdot \frac{1}{1 - e^{-\frac{c_2}{\lambda T_0}}} \right]. \quad (\text{V: 2})$$

Here C is the measured colour-equivalent, C_0 the same for the standard, T and T_0 the corresponding temperatures, λ the mean wavelength for the spectral region (expressed in microns) and $c_2 = 14320$. The factor 0.316 is obtained as $2.5 \log_{10} e \left(\frac{1}{0.3912} - \frac{1}{0.4415} \right)$.

Before using the formula (V: 2) we have to determine the constants C_0 and T_0 . For this purpose I have used the temperature at which the Balmer lines attain their maximum. According to the results obtained at Harvard compared with my own diagrams, I have adopted the temperature $10,000^\circ$ for $C = 0.25$. The maximum corresponds strictly to $C = 0.23$ according to my measurements (Fig. 12 and 13), but as the maximum is not very well defined I have used the value $C = 0.25$ which makes the theoretical relation between C and $\frac{c_2}{T}$ coincide with the empirical one

¹ According to Gerasimovic, some of the early B stars seem to show the inverse effect, i.e., too strong intensities in the violet.

Table IX.

C	$\frac{c_2}{T}$ (theoretical)	$\frac{c_2}{T}$ (BRILL 1924)
0.00	0.48	0.45
0.05	0.69	0.68
0.10	0.88	0.85
0.20	1.25	1.14
0.30	1.60	1.40
0.40	1.94	1.66
0.50	2.26	1.90
0.60	2.59	2.15
0.70	2.91	2.40
0.80	3.23	—

for high temperatures. With the constants thus obtained I have calculated the above Table IX giving $\frac{c_2}{T}$ as function of C when the latter is regarded as a Planckian gradient. In the last column I have given the corresponding $\frac{c_2}{T}$ values according to Fig. 10. A comparison between the two kinds of $\frac{c_2}{T}$ values show a good agreement for high temperatures, but for lower temperatures the theoretical $\frac{c_2}{T}$ values are systematically too great. This is shown in Fig. 10, where the theoretical relation is given by the dotted line. As BRILL's temperature scale seems to be very nearly correct, the deviation of the theoretical curve from the empirical one points out that the quantity C is not merely a Planckian gradient. The deviation is, however, not very great, and as to its essential features C may be regarded as a true temperature measure.¹

We may sum up this chapter in the following statement: *The quantity C , that is the magnitude difference between the wavelengths λ 3912 and λ 4415, has been shown to be a good colour equivalent though it deviates somewhat from a true Planckian gradient.*

¹ The deviation is reduced by about one half if the empirical curve is based on the temperatures given by RUSSEL, DUGAN, and STEWART. Compare the note on page 40.

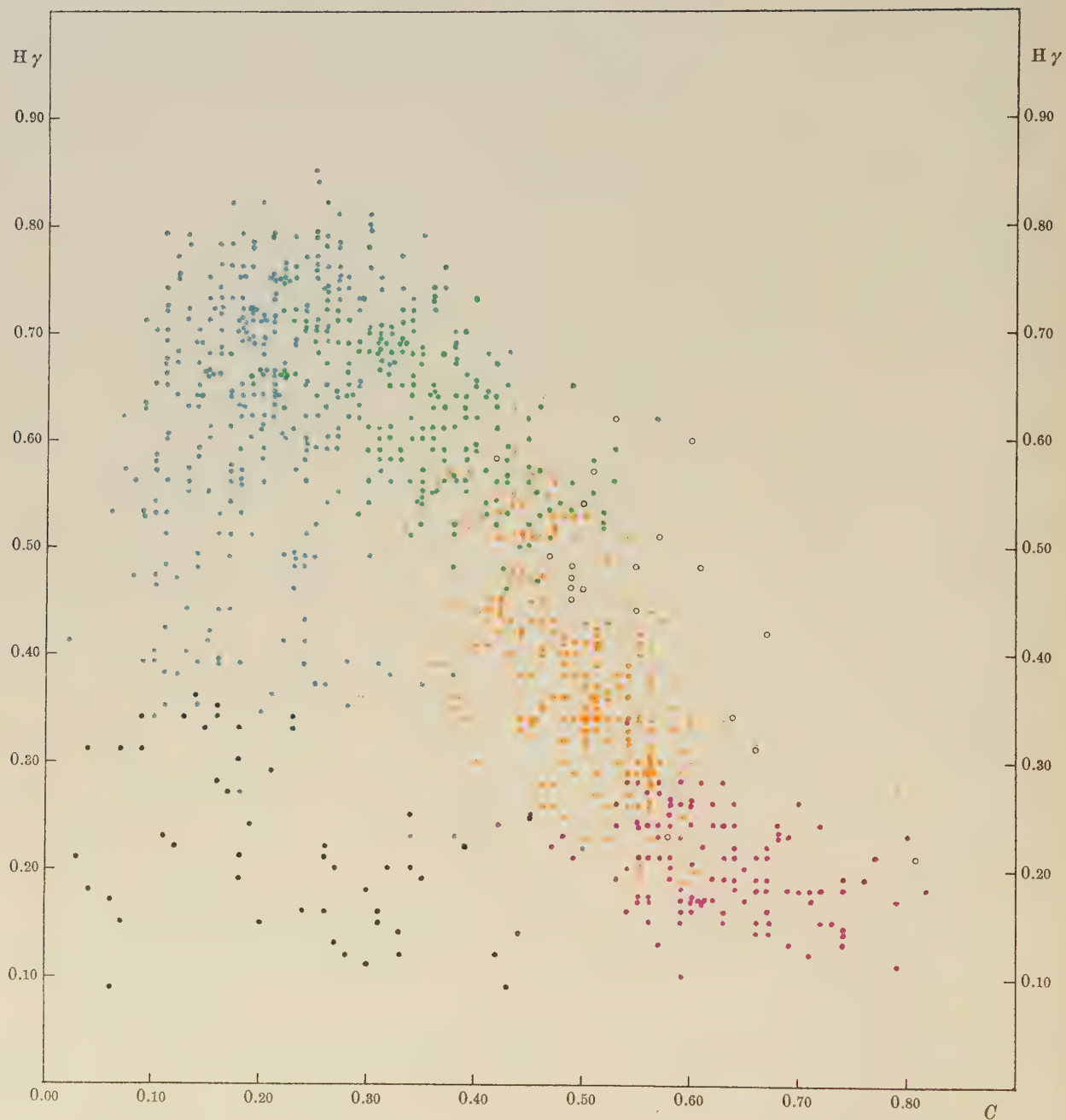


Fig. 12. Intensity of $H\gamma$ as function of the colour-equivalent C . ● are early B stars, ● B 8—A 0 stars, ● A 2—A 3 stars, ● A 5—F 2 stars, ● F 5—F 8 stars. ○ are F stars with a faint K -line designed by F 0 [A 2] and similarly.

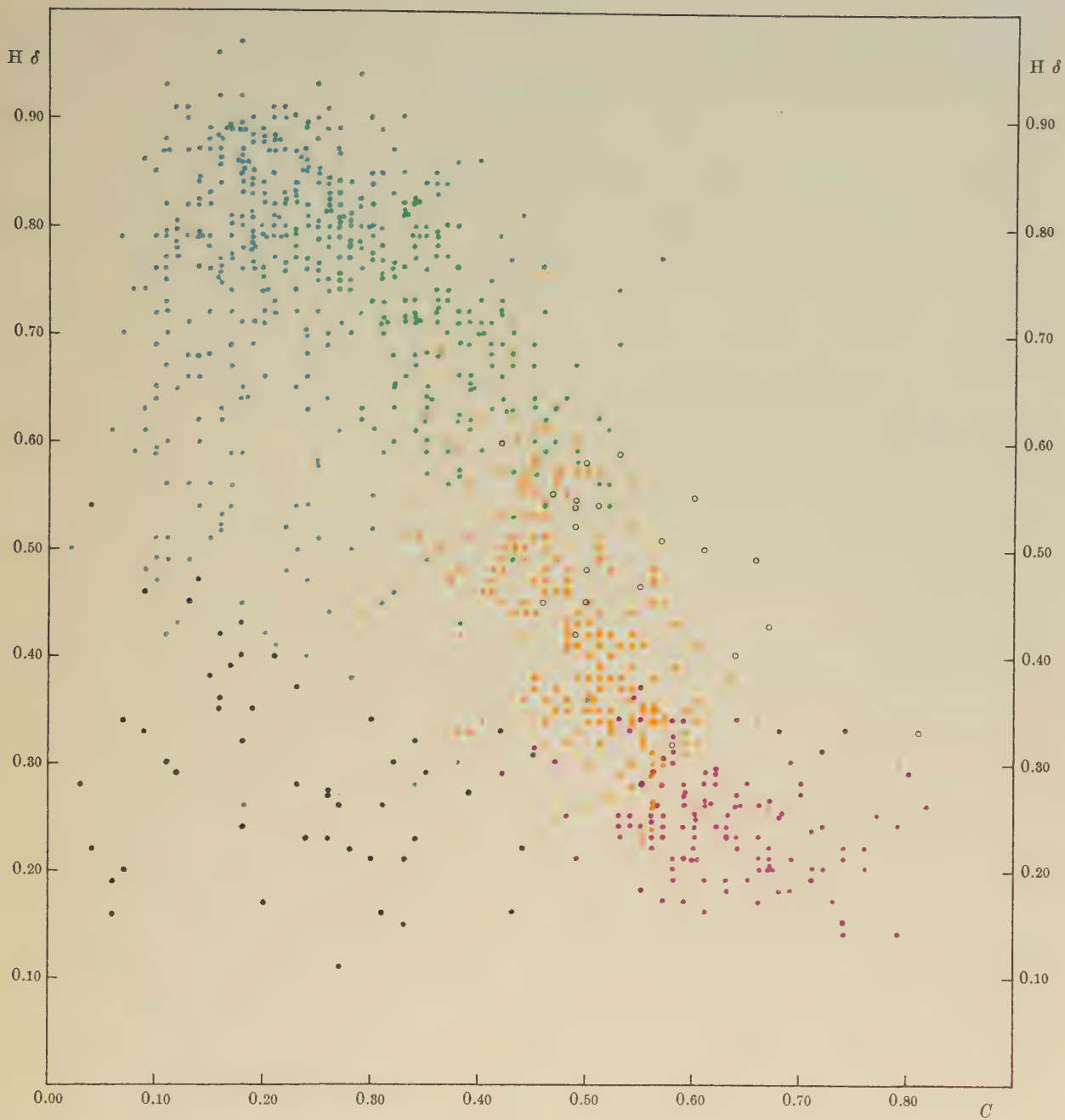


Fig. 13. The intensity of H δ as function of the colour-equivalent C . ● are early B stars, ● B 8—A 0 stars, ● A 2—A 3 stars, ● A 5—F 2 stars, ● F 5—F 8 stars. ○ are F stars with faint K -line designed F 0 [A 2] and similarly.

CHAPTER VI.

The Relationship between Hydrogen Line Intensity, Colour, and Luminosity.

The chief aim of the present investigation, as pointed out earlier, has been a study of the relation between hydrogen line intensity, colour, and luminosity. The works of LINDBLAD and SCHALÉN have shown that the intensities and wings of the hydrogen lines for B and A stars are intimately connected with absolute magnitude. The spectral classes may thus be divided into subtypes (τ , $\tau-$ etc.) characterizing the hydrogen lines and at the same time the absolute magnitudes of the stars. In a previous work¹ I showed that the luminosity classes correspond to definite measure numbers of total line absorption for stars with low colour. This is also evident from the work of Miss WILLIAMS.² As to A stars with advanced colour and strong hydrogen lines the absolute magnitude has been shown by LINDBLAD to depend on the colour. By replacing the classification by accurate measurements of line absorption and colour we may thus expect to get a good method for determining stellar luminosities of B and A type stars. In the present work I have not confined myself to B and A stars alone but have also measured F type stars. This extension of the material has been found very happy because analogous luminosity criteria have been detected also for the F type stars. At the same time, an interesting discrepancy between A and F type stars has come to view.

1. *Hydrogen line intensity as function of colour.* The distribution of the zone stars with regard to hydrogen line intensity and colour is given in Fig. 12 and Fig. 13. Here the stars are plotted with the colour equivalent C as abscissa and the intensity of $H\gamma$ and $H\delta$ as ordinate. The different spectral groups have been denoted by dots of different colour.

The figures show some interesting features. There is on the whole a marked relation between total line absorption and colour. This is most clear to the right in the figures; to the left the points are more scattered. The general run of the points agrees fairly well with the curves recently given by Miss PAYNE³, though the hydrogen line maximum is situated a little more to the left in my figures. The maximum is, however, not very well defined. It is situated at about $C = 0.23$ for both lines, corresponding to a temperature of $11,700^\circ$ according to the empirical curve in Fig. 10, based on BRILL's scale.

The different spectral type are confined to certain regions in the figures and form together a natural sequence. The spectral types used here are classified by me but they agree on the whole very well with Harvard types.

¹ Medd. Astron. Observ. Upsala No. 33, 1927.

² Harvard Circular 384.

³ CECILIA H. PAYNE, Summary of a Spectrophotometric Survey of the Stellar Sequence, Harvard Bull. 874, 1930.

The number of stars per unit area is much greater in the regions of maximum intensity and in the low temperature branch than in the region to the left in the figures. When reducing the apparent density to space density this effect would be much more pronounced, the stars to the left being the most luminous ones.

The central part of the figures show very few stars. The branches to the right and to the left are thus well separated. The early B stars show remarkably strong variation in colour. The advanced colour among some of these stars is probably due to space reddening, as the next chapter will show.

In the part of the figures corresponding to $H\gamma = 0.49$, $H\delta = 0.54$ and $C = 0.45$ these seems to be some sort of break and displacement in the low temperature branch. To base such a statement upon these figures alone would perhaps be to jump at conclusions but indeed this break is the same as comes to view in Fig. 11 as a colour excess of the A3—A5 stars (Harvard types). As will be seen later, this point in the diagram is a critical one as regards colour, luminosity, and the motions of stars.

2. *Luminosity criteria.* We now pass to the problem of finding the relation between the luminosities of the stars and their position in figures 12 and 13. When deducing such a relation we want the absolute magnitudes of the stars. But since very few individual luminosities among the zone stars are known from trigonometric parallaxes or spectroscopic criteria, we must try to find our relation by indirect means. I have proceeded in the following ways.

For the zone stars proper motions are available from the Greenwich Astrographic Catalogue Vol. 5, 1929. These proper motions may be used to find the mean absolute magnitude for stars situated in the same region of the figures. Such mean absolute magnitudes could be derived by using the parallactic motion, but this method is somewhat dangerous, particularly because of the Ursa Major drift's affecting the motions and making the luminosities come out too high. The parallactic motion was therefore used only for the B stars and most luminous A stars. The total proper motion, however, when reduced to a certain apparent magnitude, itself gives a measure of absolute magnitude for a group of stars. Such average proper motions have been calculated and by means of these the general variation of the absolute magnitude within the figures 12 and 13 could be obtained.

In order to derive the final luminosity relation, I have used the Upsala luminosity classes empirically converted to line intensities, besides mean absolute magnitudes derived from proper motions and measurements of bright F stars with well known luminosities.

a. *Results from proper motions.* We may begin with a discussion of average proper motions: The proper motions of the Greenwich Astrographic Catalogue Vol. 5 have been reduced to the photographic magnitude 8.0 (on the International scale) by multiplication by

$$f = 10^{\frac{1}{5}(m-8.0)}. \quad (\text{VI: } 1)$$

Average reduced total proper motions have then been formed for plates situated in different regions of Figs. 12 and 13. Fig. 14 shows the result of this calculation. The ordinate $H\gamma$ in this diagram is the mean between the directly measured intensity of $H\gamma$ and the corresponding value of $H\delta$ reduced to $H\gamma$ by empirical relations. (Figs. 28 and 29.) The different groups of stars are represented by circles, the areas giving the numbers of stars and the positions giving their average

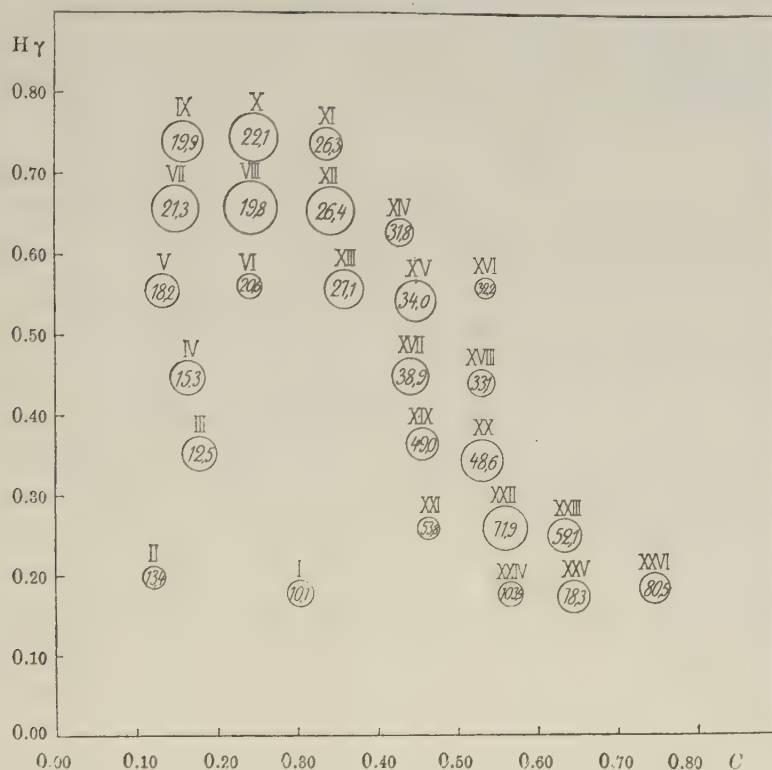


Fig. 14. The relationship between intensity of $H\gamma$, colour (C) and reduced proper motion. The figures within the circles denote average reduced proper motion (magnitude 8.0). The size of the circle represents the number of stars.

situation. The greatest circle, VIII, represents 67 stars, the smallest one, XVI, only 11 stars. In the formation of the means a few stars to the left of XVII have been excluded and also such F stars which show an abnormally faint K line (denoted by F 2 [A 3]). Finally the numbers within the circles give the average total proper motions expressed in $0''.001$ as unit.

An inspection of Fig. 14 shows roughly the general variation in absolute magnitude from point to point within the diagrams. Starting with the group I we find here the smallest proper motion, that is, the highest luminosity. The proper

motion indicates a higher luminosity for the yellowish B stars than for the white ones, a result which agrees with that found by GERASIMOVIC.¹ These small proper motions are indeed very uncertain, but the same effect comes to view in the parallactic motion, as will be seen later. It is also worth remembering that the yellowish group includes apparently fainter stars than the white one. Errors in the proper motion would thus tend to produce an effect of the opposite kind. The

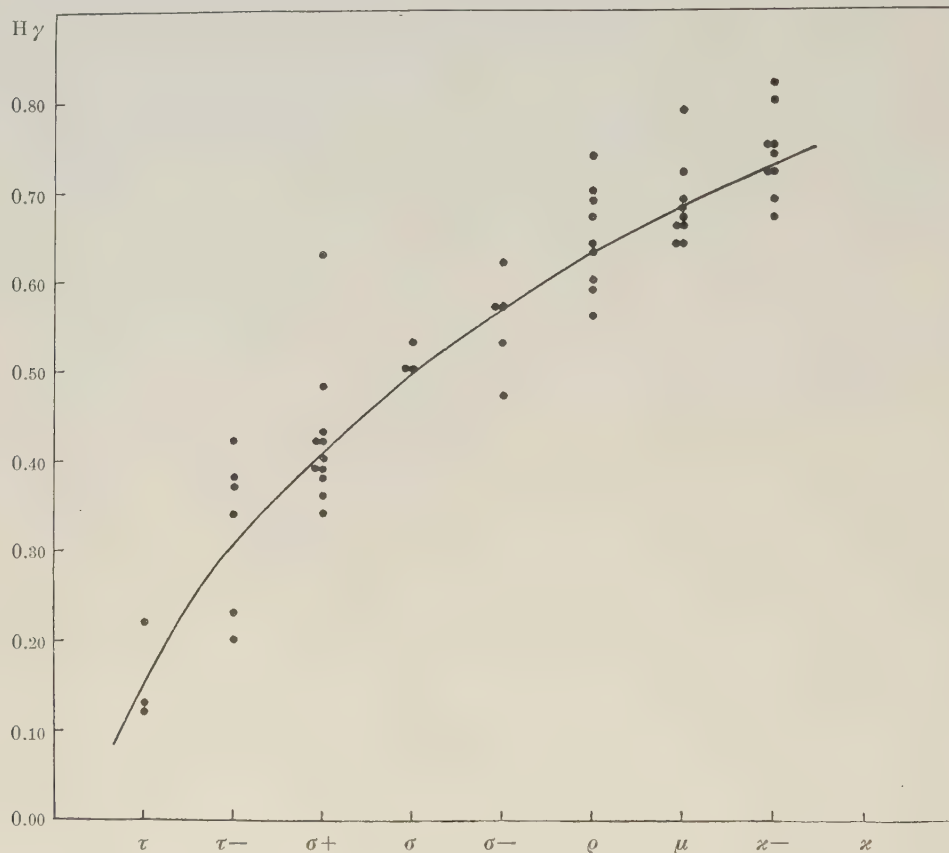


Fig. 15. Intensity of $H\gamma$ as function of Upsala luminosity class for all B and A 0 stars with $H\gamma < 0.50$ and other B and A stars of small colour ($C < 0.25$).

question arises, however, whether the luminosity effect is a real dependence between luminosity and temperature or merely caused by a combination of space reddening and different selection. This problem is discussed on page 52 and in Chapter VII.

When proceeding upwards to the groups III, IV, V and VII we find an increase in proper motion, that is, a decrease in luminosity. This variation in absolute magnitude corresponds to the variation between the Upsala luminosity classes τ to ρ .

¹ B. P. GERASIMOVIC, Harvard Circular 339, 1929.

The six groups V—X all show nearly the same proper motion, indicating no variation in the mean absolute magnitude between these groups.

When proceeding to the left from this region to the groups XI, XII and XIII, we find a decrease in luminosity with increasing colour. The effect is extended to

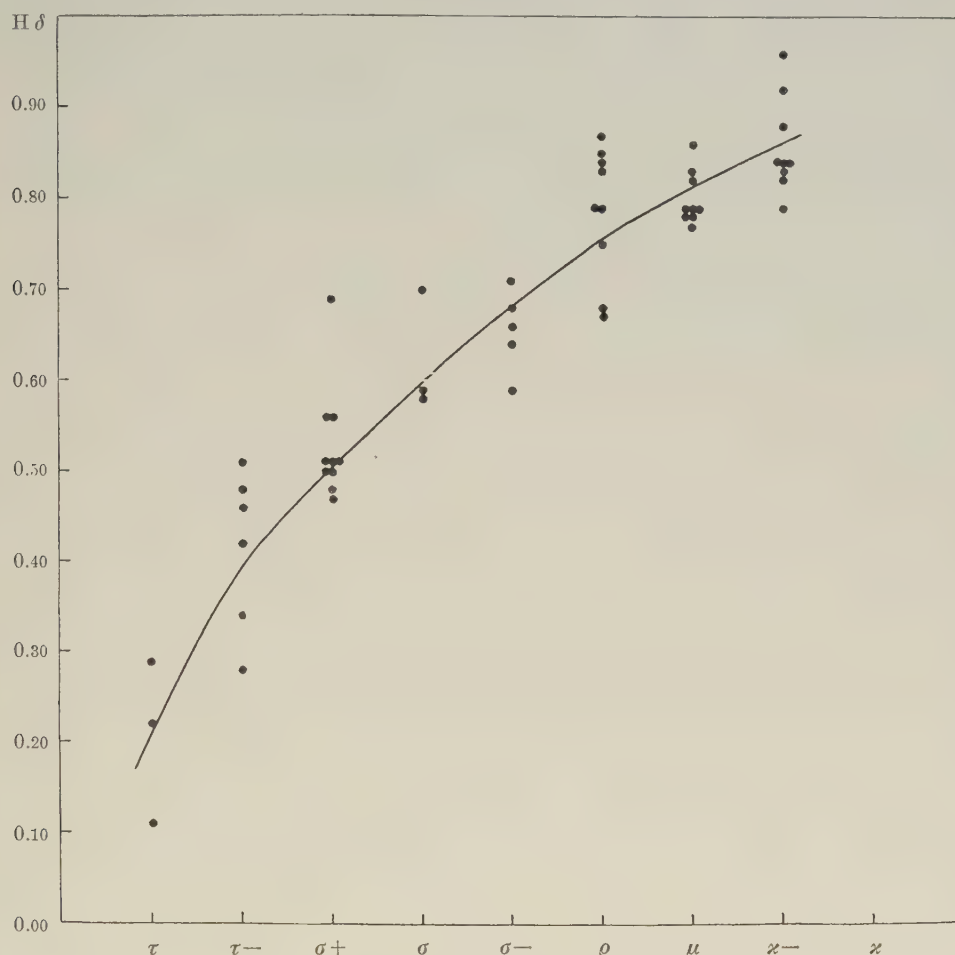


Fig. 16. Intensity of $H\delta$ as a function of Upsala luminosity class for all B and A 0 stars with $H\gamma < 0.50$ and other B and A stars of small colour ($C < 0.25$).

XIV and XV. This variation in luminosity corresponds to the transitions $\mu-x$ in luminosity class.

From the group XIV downwards there is a strong increase in proper motion. The same is evident from XVI downwards. On the other hand there is a faint effect of decrease in proper motion with increasing colour among these groups. In the low temperature branch of the diagram, decreasing line intensity corresponds accordingly to decreasing luminosity, decreasing temperature on the other hand

seems to correspond to increasing luminosity. Indeed, such effects have recently been predicted by MILNE from theoretical considerations.¹

b. Upsala classes τ - ϱ . We shall now try to convert Fig. 14 into a diagram between absolute magnitude, hydrogen line intensity, and colour. We begin with the high temperature branch. As mentioned earlier there exists a pronounced correlation between the Upsala luminosity classes and total absorption in the hydrogen lines. This fact is presented in Fig. 15 and Fig. 16 giving the relation between hydrogen line intensity and luminosity class for all B and A stars with $H\gamma < 0.50$ and other B and A stars of small colour ($C < 0.25$). The comparison is based partly on zone stars common to the list of bright stars given by LINDBLAD and SCHALÉN², partly on the Pleiades and Perseus cluster³, and finally on some zone stars common to an extensive catalogue given by SCHALÉN.⁴

As a rule the points are pretty regularly placed. The $\sigma+$ star showing the greatest deviation from the curves is the star B.D. 69° 850. According to a personal communication from Dr. SCHALÉN this star seems to have been classified too early.

The Figures 15 and 16 may be converted into diagrams between line intensity and absolute magnitude by the Table III in the above-mentioned work of LINDBLAD and SCHALÉN. Their determinations are based on a discussion of the velocities of Boss stars as well as results from various moving clusters and trigonometric parallaxes. Fig. 17 shows the relation to absolute photographic magnitude obtained for $H\gamma$ when the points corresponding to different luminosity classes are joined. In the construction of this curve the mean of $H\gamma$ and reduced $H\delta$ has been taken. The visual absolute magnitudes have been reduced to photographic ones by the colour index -0.1 for τ and $\tau-$ stars, 0.0 for $\sigma+$ to μ stars. The crosses in Fig. 17 refer to determinations from the parallactic motion described in the following.

c. Results from the parallactic motion. The parallactic motion has been used to derive mean absolute magnitudes only in the case of the most luminous B and A stars. For other hydrogen stars, the presence of the Ursa Major stream seems to imperil this method.

When computing the parallactic motion I have used SMART's charts in order to obtain the angular distance λ from the sun's apex and the position angle χ for the antapex. The charts are constructed for the co-ordinates R.A. $18^h 0^m$, Dec. $+34^\circ$ of the apex. These coordinates seem to come fairly near the apex accepted for B stars.⁵

¹ E. A. MILNE, Bakerian Lecture, 1929.

² B. LINDBLAD and C. SCHALÉN, Medd. Astr. Observ. Upsala. No. 17, 1927.

³ Y. ÖHMAN, Medd. etc. No. 33, 1927. The line intensities given in this work are to be reduced with 4.3% to be brought in concordance with the scale of the present work. Compare page 24. As to the Pleiades the new determinations given in Catalogue II have been used.

⁴ C. SCHALÉN, Medd. etc. No. 37, 1928.

⁵ Compare C. SCHALÉN, Medd. etc. No. 33, 1926.

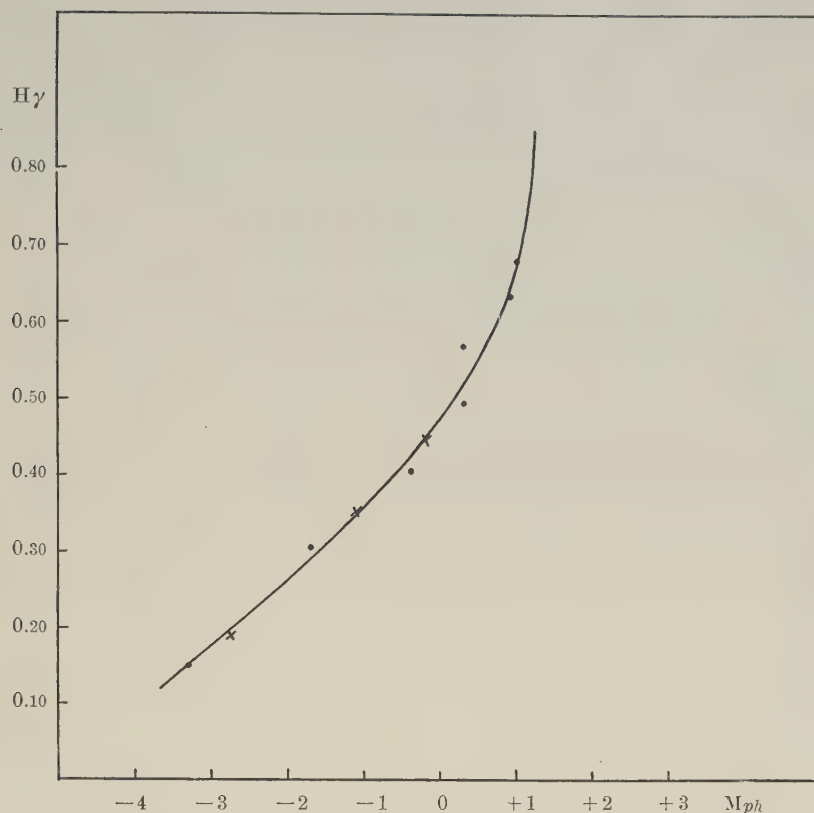


Fig. 17. Intensity of $H\gamma$ as a function of absolute photographic magnitude. (High temperature branch.) The points refer to determinations from Upsala luminosity classes, the crosses to results from the parallax motion.

Only stars brighter than the photographic magnitude 9.0 have been used, the proper motions of the fainter stars being too uncertain. The proper motions μ_α and μ_δ have been reduced to the photographic magnitude 8.0, μ'_α and μ'_δ , by using the formula VI: 1. The parallax components, v' in the direction of the sun's antapex and τ' at right angles to this direction have then been computed from the formula:

$$\left. \begin{aligned} v' &= \mu'_\alpha \sin \chi + \mu'_\delta \cos \chi \\ \tau' &= -\mu'_\alpha \cos \chi + \mu'_\delta \sin \chi \end{aligned} \right\} \quad (\text{VI: 2})$$

Adopting the value 21.2 km./sec. for the solar velocity¹ the mean parallax for a group of stars is finally found from

$$\bar{\pi} = 0.223 \cdot \frac{\sum v' \sin \lambda}{\sum \sin^2 \lambda} \quad (\text{VI: 3})$$

¹ The same value as used by SCHALÉN, loc. cit. on page 50.

The computation has given the results collected in Table X. In the two first columns are given the limits of the groups as to $H\gamma$ and C , with the mean values in parenthesis. Then follow $\frac{\Sigma v' \sin \lambda}{\sin^2 \lambda}$, the mean of τ' , the mean absolute photographic magnitude with mean error, and finally the number of stars.

Table X.

$H\gamma$	C	$\frac{\Sigma v' \sin \lambda}{\sin^2 \lambda}$	$\overline{\tau'}$	M_{ph}	n
< 0.29 (0.18)	> 0.23 (0.30)	0''.00162	-0.0012	-4.2 ± 1.8	15
< 0.29 (0.20)	≤ 0.23 (0.12)	0.00517	+0.0004	-1.7 ± 1.8	13
< 0.40 ≥ 0.29 (0.35)	< 0.36 (0.18)	0.00664	-0.0017	-1.1 ± 0.8	29
< 0.50 ≥ 0.40 (0.45)	< 0.29 (0.16)	0.01022	+0.0002	-0.2 ± 0.5	28

The two first groups show the same effect as was found from the average proper motions, that yellowish B stars are more luminous than withish ones. The determinations are, however, uncertain and too much stress should not be laid on these values. We must also remember the possible influence of absorption in space. If the yellowish stars have got their advanced colour by absorption in space their apparent magnitudes have been considerably affected by a general absorption. When reducing the proper motions to the magnitude 8.0 we thus introduce an error giving the yellowish stars too high proper motions and thus a too faint luminosity. On the other hand the space reddening will produce a selection favouring the most luminous stars. These two effects will thus tend to balance. But a rigorous treatment of this problem is not possible at present.

The mean absolute magnitudes obtained above agree very well with the determinations of LINDBLAD and SCHALÉN, as is seen from Fig. 17, where they are plotted as crosses. For the two first groups the mean magnitude $M = -2.7$ has been used. The results from the parallactic motion thus give a confirmation of the relation obtained from the luminosity classes.

d. The Pleiades. It may appear quite natural to control Fig. 17 by means of the physical members of the Pleiades. All these stars are situated at the same distance and the relation may thus come directly out from the apparent magnitudes.

A list of the Pleiades is given in Catalogue II. From this catalogue, the line intensities have been taken and plotted against apparent photographic magnitude.

The result is shown in Fig. 18, where the relation of Fig. 17 has been given by the dotted line corresponding to the parallax $0''.0063$ recently determined by SCHWASSMANN.¹

As is seen from this figure, the points are situated very close to a smooth curve, but the curve does not coincide with the dotted line giving the relation found above. This remarkable result seems to point out that *the physical structure*

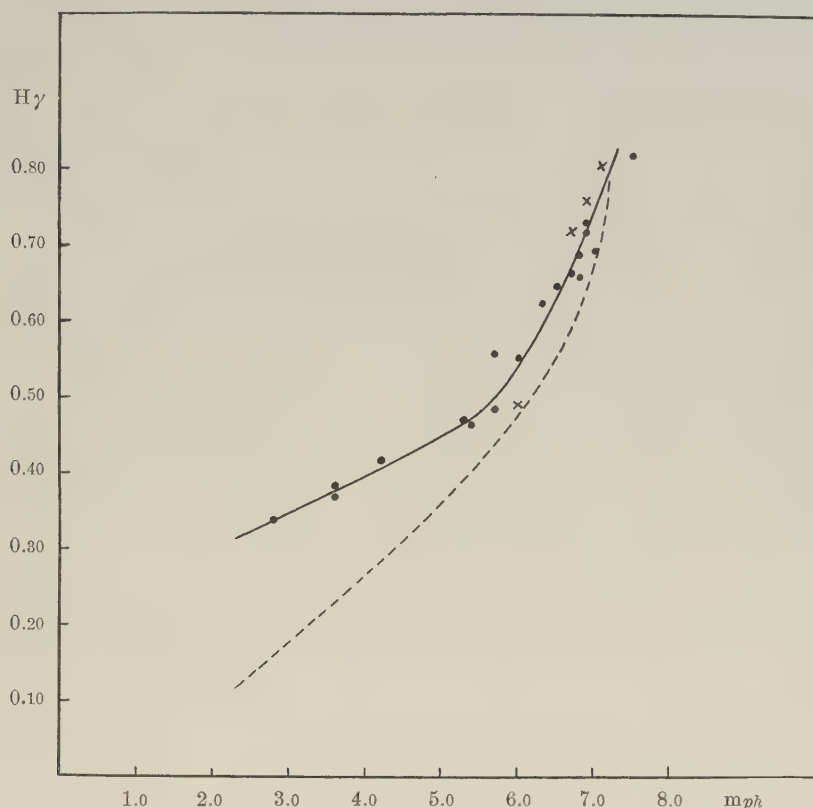


Fig. 18. Intensity of $H\gamma$ as a function of apparent photographic magnitude for Pleiades stars with $C < 0.20$. Points are physical members according to both HERTZSPRUNG and TRUMPLER. Crosses are physical members according to TRUMPLER situated more distant than 1° from Alcyone. The dotted line gives the relation of Fig. 17, valid for ordinary stars.

of the Pleiades stars is different from that of stars in general. This result may well agree with the fact that clusters often show some abnormally bright B and A stars.

From the above result we may conclude that the relation between hydrogen line intensity and absolute magnitude varies for different groups of stars. The question arises: Do the stars in general form a homogeneous group in this respect? The small dispersions in absolute magnitude found by LINDBLAD and SCHALÉN for

¹ A. SCHWASSMANN, Die Spektren der Pleiadensterne bis zur photographischen Grösse 14.0, Mitteilungen der Hamburger Sternwarte in Bergedorf, Band 6, No. 31, 1930.

the different luminosity classes tell in favour of such a homogeneity, but we are not sure this is always the case. To apply spectroscopic criteria to stars in clusters may evidently sometimes lead to errors.

Fig. 18 is of interest as to the question of the origin of a stellar cluster. It seems from the above that the Pleiades stars have a common origin and that the cluster has not been formed by an accumulation of stars.

e. Upsala classes μ - κ . We now proceed to those stars in Fig. 12 which show maximum absorption in the hydrogen lines. It has been established in Fig. 14 that there is a dependence between colour and luminosity for these stars. This effect corresponds to the variation in luminosity between the Upsala classes μ , κ - and κ which are primarily distinguished by different steps in colour. A calibration of the luminosity scale may thus obviously be made by determining mean colour indices for the different luminosity classes.

A comparison between colour and luminosity class has been performed in Table XI. I have proceeded in three different ways. For such μ , κ - and κ stars classified by LINDBLAD and SCHALÉN which are present in my catalogues, a direct comparison has been possible. Unfortunately only a few stars in the zone are common with the catalogues of LINDBLAD and SCHALÉN. I have therefore also included the earlier measurements of the Pleiades and stars in other parts of the Greenwich zone. The use of the Pleiades may seem dangerous according to the results above. However, no marked deviation in the colour relation could be detected for these stars.¹ The first row in Table XI gives the results of this comparison. The number of stars are given in parenthesis.

For a number of stars in the list given by LINDBLAD and SCHALÉN colour indices are available from HERTZSPRUNG'S compilation and BOTTLINGER'S catalogue. The second and third rows in Table XI give mean values of C obtained from these catalogues. The $\frac{C_2}{T}$ values given by HERTZSPRUNG and BOTTLINGER have been reduced to BRILL'S scale and then converted to corresponding C values with the help of Fig. 10 of Chapter V.

Table XI.

	μ	A 0 κ -	A 2-A 3 κ -	A 2 κ	A 3 κ
Direct determinations of C . .	0.18 (10)	0.18 (8)	0.27 (17)	0.35 (4)	0.32 (5)
C obtained from HERTZSPRUNG	0.17 (11)	0.13 (1)	0.31 (12)		0.37 (3)
C " " BOTTLINGER .	0.23 (3)		0.33 (8)		0.38 (3)
Mean	0.18	(0.18)	0.30	(0.35)	0.35

¹ The C -values of the brighter stars in the Pleiades seem to be systematically a little too small.

As is seen from this table, there is a very pronounced correlation between luminosity classes and colour. On the whole, the different determinations agree well. This circumstance may also be taken as a confirmation of the relation between C and $\frac{c_2}{T}$ given in Fig. 10.

In the construction of the definite luminosity diagram Fig. 22 use have been made of Table XI and the absolute magnitudes given by LINDBLAD and SCHALÉN.¹ The

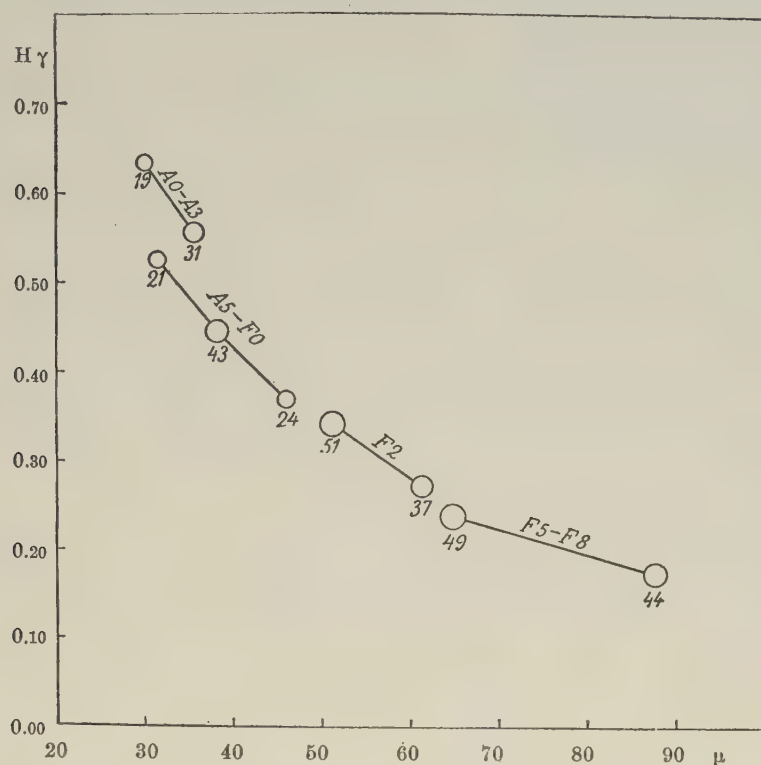


Fig. 19. Intensity of $H\gamma$ as a function of average proper motion μ for different spectral types (colour interval $0.40 \leq C < 0.70$).

mean values of C for the different classes have all been increased by 0.03 which gives a better agreement with the proper motion data. This correction seems justifiable also from the systematic errors possibly introduced by the stars taken from my earlier work. The relation obtained between colour and luminosity may still be regarded preliminary and for advanced colours all A type stars have been given the absolute magnitude +2.5 as is seen in Fig. 22.

f. The low temperature branch. The relation between absolute magnitude, hydrogen line intensity and colour in the low temperature branch remains to be investigated. According to Fig. 14 decreasing line intensity is accompanied by

¹ Loc. cit. on page 50.

decreasing luminosity; increasing colour with constant line intensity on the other hand, by an increase in luminosity, but the latter effect is very faint.

According to Fig. 12 and Fig. 13 a decrease in line intensity corresponds on the average to a displacement along the spectral sequence. When considering the main series in the HERTZSPRUNG-RUSSELL diagram we know there is a pronounced correlation between spectral type and absolute magnitude. We must have this relation in mind when treating the luminosity relations in the low temperature branch.

As the influence of colour on luminosity in Fig. 14 seems to be very slight for stars with the same hydrogen absorption in the low temperature branch, I have in Fig. 19 plotted average proper motions against line intensity for all the stars within the interval $0.40 \leq C < 0.70$. The stars have been grouped, however, according to spectral type. The numbers under the circles give the number of stars in the different groups.

As is seen from Fig. 19, there is a pronounced dependence between line intensity and reduced proper motion within each spectral group. The different relations coincide, however, with one and the same curve with the exception of group A0—A3. This points out that the luminosity relation is quite the same for all the spectral types A5—F8. As these spectral types generally are identified with different steps of temperature, this result speaks also in favour of a very slight dependence between temperature and luminosity for these stars when the line intensity is kept constant.

The deviation of the A0—A3 stars from the general run is very interesting. The break in the curve does not look very marked, but it is remarkable that it corresponds to the displacement in the low temperature branch found in Fig. 12 and 13. Moreover, we must in this connection notice a result as to the velocity distribution of stars of different spectral types found by STRÖMBERG¹, LINDBLAD², and PETERSSON³. The point of discontinuity seems, according to these authors, to correspond to a shift in the general velocity distribution of the stars, a large proportion of the A0—A3 stars moving in the direction of the Ursa Major stream. As the direction of motion of the Ursa Major stream coincides nearly with the direction of the sun's motion, the average proper motions of the A stars will give too high luminosities for these stars. The break in the general curve of Fig. 19 will thus mean a considerable discontinuity as to absolute magnitude. Another reason why the break does not appear so distinctly from the proper motions is probably that the two kinds of stars are somewhat mixed in the diagram. That

¹ G. STRÖMBERG, Distribution of the Velocities of Stars of Spectral type A, Mount Wilson Contr. No. 257, 1922.

² B. LINDBLAD, Nova Acta Reg. Soc. Scient. Upsaliensis, Ser. IV, Vol. 6, No. 5, p. 56, 1925.

—, The velocity Ellipsoid, Galactic Rotation, and the Dimensions of the Stellar System, Montly Notices 90, No. 5, 1930.

³ H. PETERSSON, Medd. etc. Upsala, No. 29, p. 30, 1927.

is surely the reason why the break does not appear in Fig. 14. The break is present as a marked shift in the frequency curve of proper motions.

In order to test this question by another method and fix the luminosity relationship in the low temperature branch, I have investigated a number of F type stars for which luminosities have been spectroscopically determined at Mount Wilson. For some of the bright stars in the zone investigated by me Mount Wilson data are available. To extend the material I have taken spectra of some bright F stars scattered over the north celestial hemisphere. A list of all these stars is given in Table XII. The first column contains B.D. number, the second, the Boss or Cincinnati number. The third and fourth give photographic magnitude and Upsala spectral type. For the Greenwich zone stars, the photographic magnitude is Greenwich magnitude reduced to the International scale. For other stars the Harvard visual magnitude has been reduced to the photographic by adding the colour index $= 1.40 C - 0.32$. This relation has been deduced from Fig. 10 and refers to KING's scale.¹ The fifth column gives the mean of $H\gamma$ and reduced $H\delta$ with the number of images within parenthesis. Then the colour equivalent C is given. In the case of the zone stars, it is the measured quantity. As to the others stars, it has not been possible to use the measured quantities because we do not know the plate sensitivity and the atmospheric transmission. The C values within parenthesis for these stars have been obtained from HERTZSPRUNG's compilation and BOTTLINGER's list by using BRILL's tables and the relationship given in Fig. 10. The same weights as in Chapter V were given to the different determinations. The photographic absolute magnitudes in the next column were obtained from the Mount Wilson visual absolute magnitudes² by using the C values and the above relation to colour index. The magnitudes within brackets are determined at Victoria³ or Norman Lockyer Observatory.⁴ The last column gives the absolute magnitudes derived by me from the hydrogen line intensities.

Fig. 20 shows a comparison between hydrogen line intensity and absolute magnitude for these stars. It will be seen that most stars are situated very close to a smooth curve. There are, however, some exceptions. One of the stars classified as A 3 by me belongs obviously to the A type stars and follows another relation (indicated by the dotted line). Moreover, some of the most luminous stars denoted by crosses are situated to the left of the curve. These stars furnish marked exceptions from the general dependence. These stars, however, are of super giant character, and comparing Miss PAYNE's⁵ relationship between hydrogen line inten-

¹ The Mount Wilson scale has not been used, as it seems to give abnormally high colour indices for the F stars.

² Mount Wilson Contr. No. 199, 1920.

³ Publ. of the Dominion Astroph. Observatory, Vol. III, No. 1, 1924.

⁴ W. B. RIMMER, The Luminosities and Parallaxes of Five Hundred and Twenty-Five Stars, Types F 0 to M b. Memoirs of the Royal Astronomical Society, Vol. LXIV, 1925.

⁵ Harvard Bulletin. No 874, 1930.

8-30736. *Nova Acta Reg. Soc. Sc. Ups., Ser. 4, Vol. VII. N:o 3. Impr. 80/10 1930.*

Table XII.

B.D.	Boss or Cinc.	m_{ph}	Sp. U.	$\overline{H\gamma}$	C	Mt. W. M_{ph}	Upsala M_{ph}
67° 98	<i>C</i> 150	7.1	F 8	0.15 (3)	0.63	4.6	4.7
69 102	327	6.0	F 5	0.22 (2)	0.61	4.3	4.0
65 239	498	6.6	F 2 [A 2]	0.26 (2)	0.58	3.7	3.5
68 200	637	6.6	F 2	0.27 (1)	0.79	—0.6	
62 654	694	3.9	F 8 [A 5]	0.37 (2)	(0.75)	0.7	
49 917	772	2.5	F 5	0.36 (2)	(0.57)	—0.7	
66 284	840	6.1	F 2	0.41 (6)	0.50	(1.7)	1.5
42 815	847	4.4	F 2	0.34 (3)	(0.56)	1.1	
66 370	1179	6.8	F 5	0.18 (2)	0.69	4.6	4.5
64 500	<i>C</i> 654	6.7	F 5	0.29 (2)	0.59	3.3	3.2
13 1396	1725	3.9	F 5	0.29 (3)	(0.56)	2.5	3.2
22 1645	1898	4.1	F 2	0.38 (3)	(0.47)	1.5	2.0
32 1562	1952	4.5	F 0	0.40 (3)	(0.42)	1.8	1.7
34 1649	2001	5.3	F 5	0.27 (1)	(0.49)	1.2	
42 1956	2413	4.5	F 2	0.28 (1)	(0.52)	3.6	3.3
67 577	2441	5.4	F 5	0.21 (1)	(0.54)	4.3	4.1
63 845	2540	4.1	F 0	0.40 (2)	(0.44)	1.6	1.7
52 1401	2552	3.8	F 5	0.22 (2)	(0.56)	3.5	4.0
59 1268	2632	4.2	F 0	0.42 (3)	(0.48)	1.8	1.5
24 2209	2730	3.9	F 2	0.44 (3)	(0.40)	0.2	1.0
56 1459	2785	5.3	F 5	0.18 (1)	(0.60)	4.1	4.4
38 2565	3722	3.2	A 3	0.60 (2)	(0.38)	2.0	2.5
67 876		5.9	F 8	0.19 (4)	0.76	(4.6)	4.4
65 1157	4322	5.4	F 5	0.18 (5)	0.58	4.1	4.4
68 947		8.2	F 2	0.30 (2)	0.59	2.9	3.0
68 949	4483	5.2	F 5	0.28 (3)	0.61	3.4	3.3
64 1252	4623	5.5	F 2	0.28 (1)	0.57	4.0	3.3
66 1446		8.6	F 5	0.23 (1)	0.57	3.8	3.9
69 1228	5723	5.7	F 2	0.32 (4)	0.54	3.1	2.8
69 1262	5823	6.0	F 2	0.41 (4)	0.48	(1.5)	1.5

sity and temperature for such stars we must indeed expect such a deviation from the relationship valid for ordinary stars. This question is illustrated by Fig. 21, which gives the distribution of the stars in a diagram between hydrogen line intensity and colour. The dotted line in this figure would correspond to Miss PAYNE's curve for supergiant stars. The full drawn line gives on the other hand the general run of ordinary F stars.

The correlation that may be noticed from Fig. 20 is quite too high to be caused by chance. One could say against it that the relation found is a relation between total absorption of $H\gamma$ and Mount Wilson luminosity criteria but no direct dependence to absolute magnitude. As the Mount Wilson magnitudes are based on the relative intensities of certain metallic lines it seems justifiable, however, to regard the relation as a true dependence upon absolute magnitude, especially as the mean error in the Mount Wilson determinations are small.

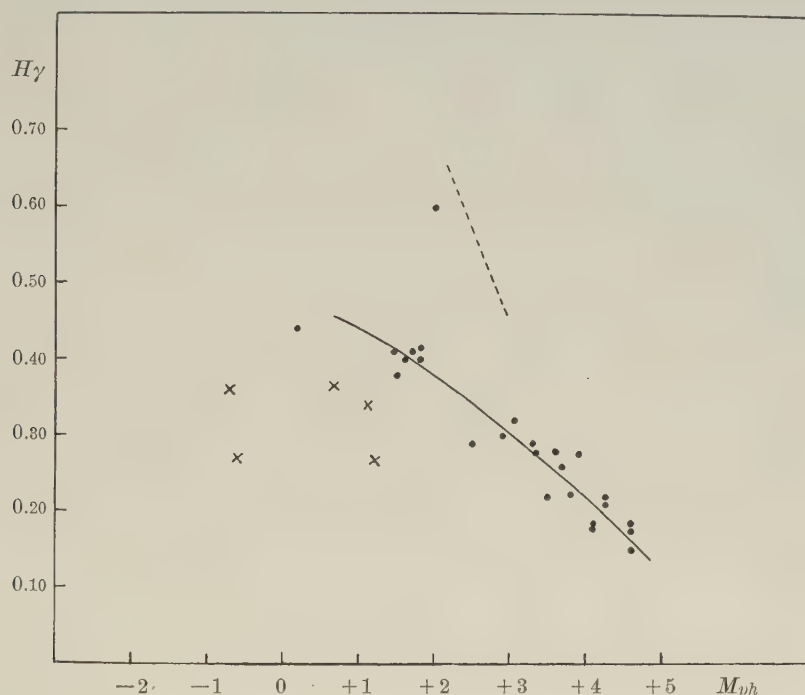


Fig. 20. Intensity of $H\gamma$ as a function of absolute photographic magnitude for F type stars. The dotted line indicates the corresponding relationship for A stars of advanced colour. The crosses denote F stars which are probably of supergiant character.

But the behaviour of the most luminous F stars offers difficulties in connection with determinations of absolute magnitudes. Some of them may be separated by means of their very advanced colour, but others can not be distinguished from ordinary F stars by small dispersion spectra. The super giant F stars, however, are rather rare.

It is necessary in this connection to pay attention to the relation between absolute magnitude and spectral type known as the main series in the HERTZSPRUNG-RUSSELL diagram. It is easy to identify the main series with the relation found in Fig. 20. Perhaps the hydrogen absorption furnishes a much better measure of temperature than the colour does, and the relation obtained is possibly only a refined main series. That the relation obtained is to some degree associated

with the main series is quite obvious. The chief point in this dependence, however, is surely not the temperature but the luminosity because otherwise the average proper motion would increase with increasing colour in the right hand side of Fig. 14.¹ Further evidence on this point is found from comparisons with the *K*-line. The *K*-line is on the whole a measure of temperature, at least when the temperature is not too low. A comparison between *C* and the *K*-line shows a better correlation than a comparison between hydrogen line absorption and the *K*-line

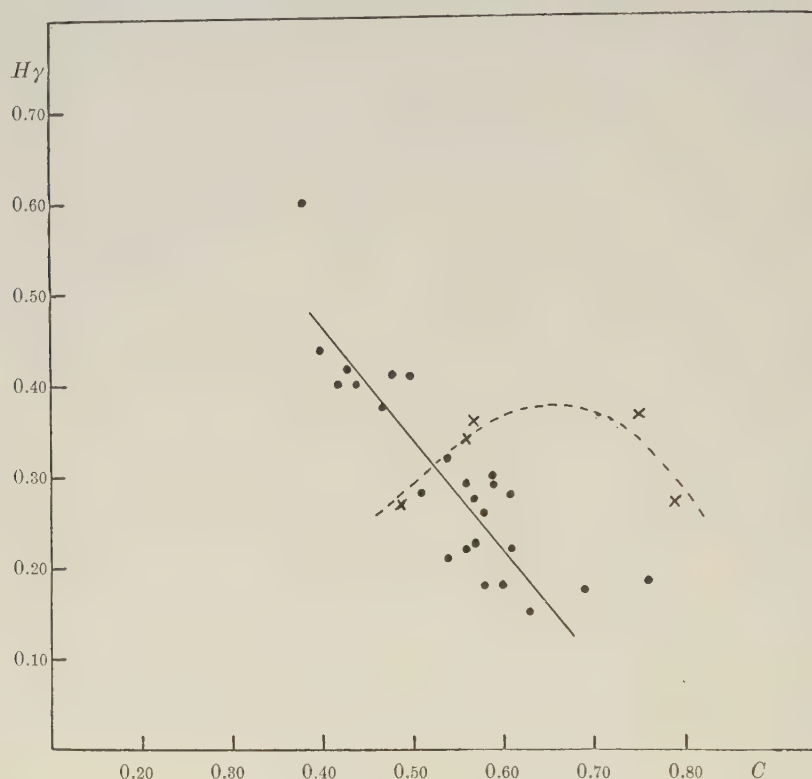


Fig. 21. Intensity of $H\gamma$ as a function of colour (C) for the stars given in Fig. 20. The fully drawn line gives the relationship for ordinary stars, the dotted curve indicates that probably valid for supergiant stars.

(compare Chapter X). As the hydrogen lines are more accurately measured than the colour equivalent C , this fact points out that the hydrogen line intensity is not as good a measure of temperature as C . It is then obvious that the relation of Fig. 20 includes a direct relation between hydrogen line intensity and absolute magnitude, and is not merely a consequence of the close relation between temperature and luminosity in the main series of the HERTZSPRUNG-RUSSELL diagram.

¹ Also the residuals in C from the full drawn line in Fig. 21 do not show any marked correlation with the residuals in M_{ph} from the curve in Fig. 20.

According to Fig. 20 the early F stars seem to have remarkably high luminosities which do not agree very well with the mean absolute magnitudes generally attributed to these types. On the other hand, some of the early F stars probably belong to the coloured A type group of low luminosity and other F stars may have faint hydrogen lines, so by these means the average luminosities for the F types may come out rather low.

g. Adopted luminosity diagram. We are now able to construct our diagram between hydrogen line intensity, colour and luminosity. Fig. 22 shows the result of assembling the data given above. It will be seen that most of the lines of constant absolute magnitude are drawn parallel to the C axis. This does perhaps not seem quite in accordance with the results above, but the slope of the lines sometimes found is rather uncertain, and it seemed to me better not to introduce these vague results. On the high-temperature side the lines should probably rise a little with increasing colour. On the low-temperature side, on the other hand, the lines ought perhaps to decline somewhat. In the top of the diagram the lines of constant luminosity proceed parallel to the $H\gamma$ axis. Probably there exists a smooth transition from these vertical lines to the horizontal ones, but thus far it has not been possible to see how the matter stands.

From Fig. 22 absolute magnitudes may thus be read off from the observed quantities $H\gamma$ and C . But in some parts of the diagram the luminosity criteria fail. That is especially the case in the region between the coloured A-type stars of absolute magnitude $+2.5$ and the bright F type stars of absolute magnitude $+1.0$. These two kinds of stars are of course somewhat mixed in this region and it is not possible to separate them from each other. Also between the absolute magnitude line 0.0 and the vertical one $+2.0$ there is a region where we do not know very much as to the absolute magnitudes.

In the low temperature branch some of the super giant F stars may finally be mixed with ordinary F stars, so their luminosities may be wrongly determined. Such super giant F stars are, however, rather rare.

h. General considerations. Some remarks remain concerning the physical interpretation of Fig. 22. Milne has recently shown¹ that luminosity effects as to the hydrogen line intensities are to be expected on the low temperature side of the maximum. Here decreasing line intensity would correspond to decreasing luminosity, decreasing temperature to increasing luminosity. On the high temperature side, on the other hand, no luminosity effects are to be expected. These results were obtained assuming the absorption coefficient κ to be connected with electron pressure P_e and temperature T according to the formula: $\kappa \sim P_e/T^{3/2}$.²

If the absorption coefficient is assumed constant, luminosity effects will appear on the high temperature side but not on the low temperature side.

Comparing these results with Fig. 22 and the diagrams given earlier, we find

¹ Bakerian Lecture, p. 449, 1929.

² Elvey has shown that $\kappa \sim P_e/T^{3/2}$ fits the observations better. *Astroph. Journal* 71, p. 207, 1930.

that the luminosity relations on the high temperature side of the maximum confirm the assumption $\kappa = \text{constant}$, but the results from the low temperature side speak in favour of $\kappa \sim P_e$.

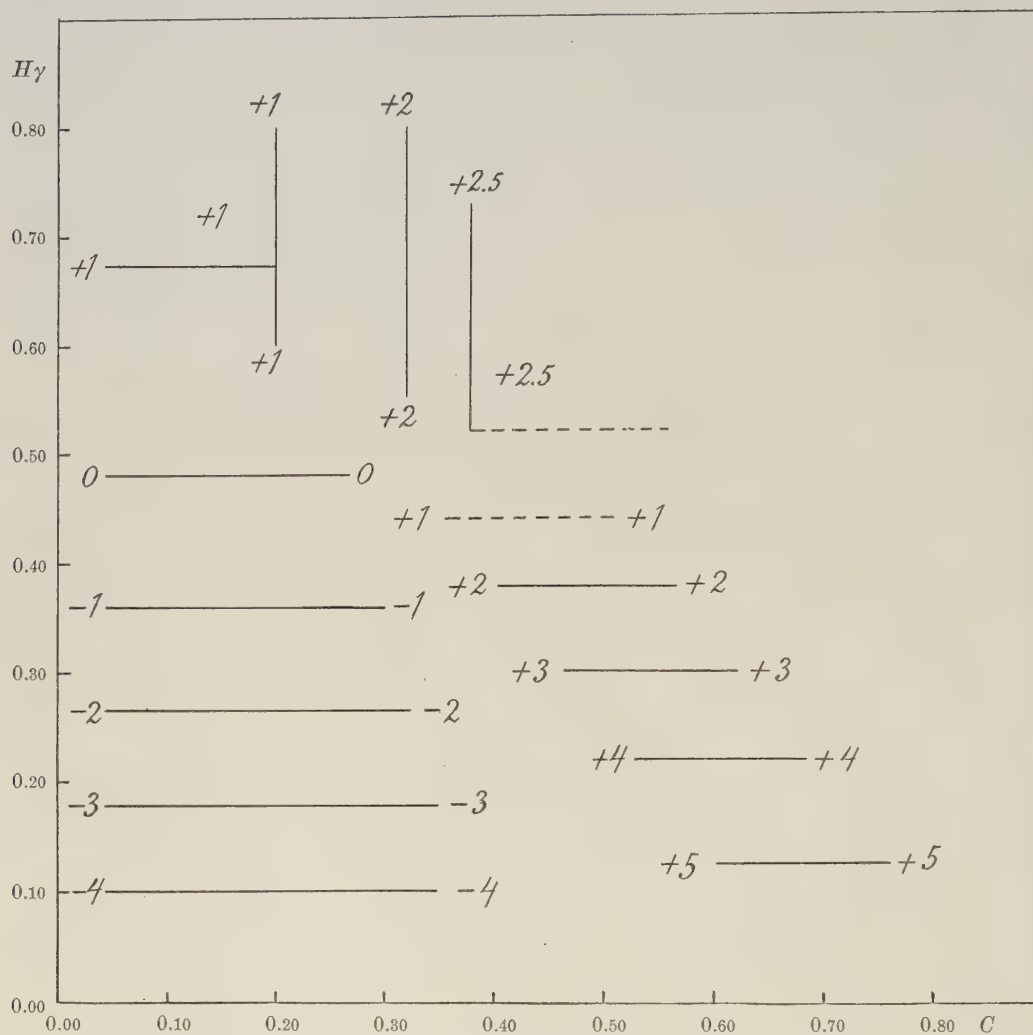


Fig. 22. Absolute photographic magnitude as a function of intensity of $H\gamma$ and colour (C).

One must, however, be careful in simply identifying the luminosity-effects found with the ones predicted by theory. It is not certain, that the luminosity effects are to be referred to a purely physical theory of the stellar atmospheres; they may also be caused by such a general relation between luminosity and temperature as that of the main series in the HERTZSPRUNG-RUSSELL diagram. Especially in the high temperature branch, precautions must be taken in this respect. The colour

is a very bad measure of temperature for these stars and the hydrogen line intensity may primarily be a measure of temperature, the variation in luminosity thus appearing as a secondary effect. Against that we could put forward such a star as α Cygni, which shows faint hydrogen lines and at the same time metallic lines. These supergiant stars, however, seem to form exceptions as to the intensity of the hydrogen lines¹ and perhaps ought not be treated with normal stars.

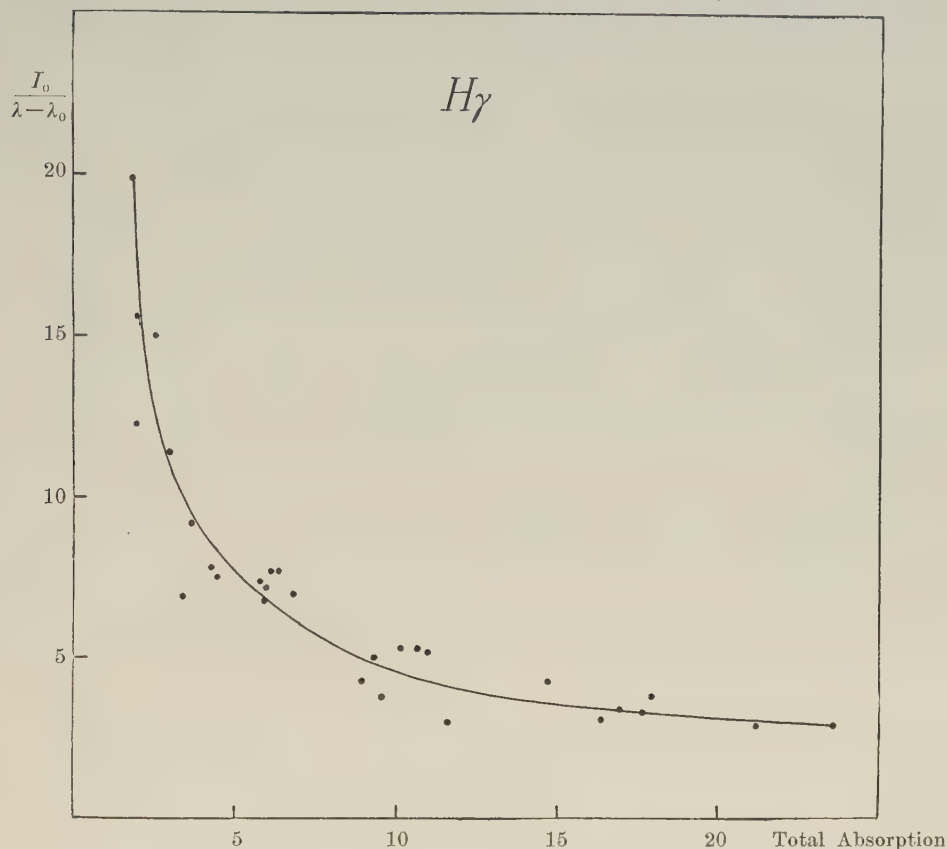


Fig. 23. ELVEY's quantity $\frac{I_0}{\lambda - \lambda_0}$ as function of total line absorption $H\gamma$.

It is necessary in this connection to pay attention to the possible influence of the Stark effect. The works of O. STRUVE², Miss WILLIAMS³, and ELVEY⁴ indicate that there is a dependence between line width and luminosity for the hydrogen lines, which is probably caused by Stark effect. If this is true, we must expect

¹ Compare page 57.

² Astroph. Journal 69, p. 173, 1929.

³ Harvard Circular 348, 1929.

⁴ The Contours of Hydrogen Lines in Stellar Spectra, Astroph. Journal 71, p. 191, 1930.

better determinations of absolute magnitude when not only the total absorption is considered, but also the shape of the line contour.

The results of Miss WILLIAMS and ELVEY are from several points of view interesting to compare with the ones presented here. Miss WILLIAMS suggests that not only the total line absorption but also the temperature is strongly correlated with luminosity on the high temperature side of the BALMER line maximum. Her statement is, however, partly reached by indirect means from a comparison between

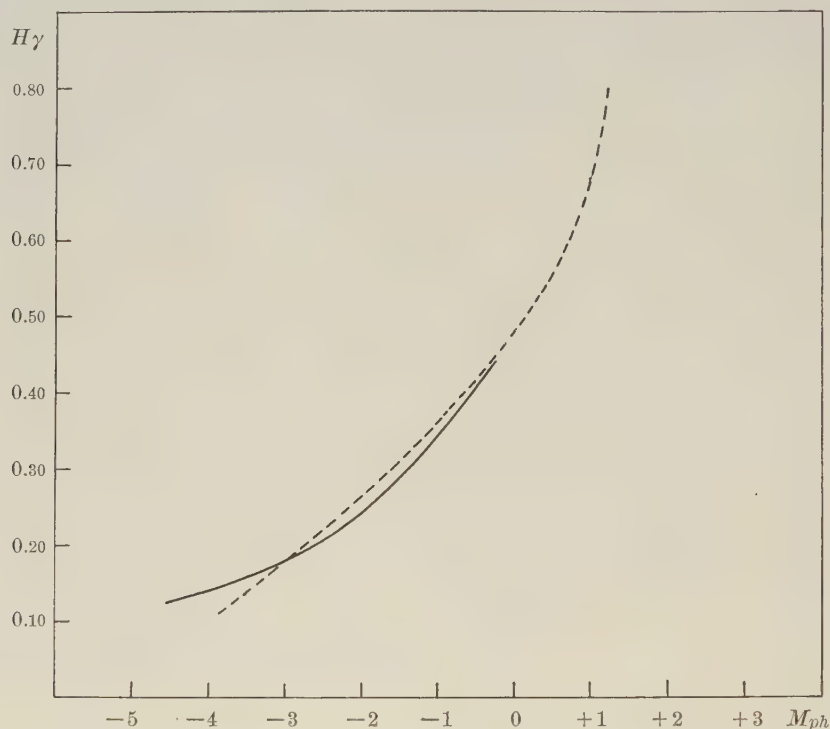


Fig. 24. Relation between intensity of $H\gamma$ and absolute magnitude obtained by transformation of ELVEY's relation between $\frac{I_0}{\lambda - \lambda_0}$ and absolute magnitude. The dotted line gives the relation of Fig. 17.

total line absorption, temperature and »line grade», the latter being found correlated to luminosity. Moreover, the number of stars in her list with well known luminosities is rather small. The small dispersion in absolute magnitude found by LINDBLAD and SCHALÉN for the different Upsala luminosity classes speak in favour of a very slight relation between colour and luminosity, that is of the correctness of the horizontal lines to the left in Fig. 22. A confirmation of this view has been found from ELVEY's investigation. He has found a good correlation between luminosity and $I_0/\lambda - \lambda_0$, I_0 being the central intensity and $\lambda - \lambda_0$ the half-width of the line at a depth of 10 per cent absorption. This effect is interpreted as due mainly to Stark broadening. When plotting the quantity $I_0/\lambda - \lambda_0$ against total line

absorption for spectral types earlier than A 2 the remarkable relation in Fig. 23 is obtained. It is thus obvious that $I_0/\lambda - \lambda_0$ is primarily a measure of total line absorption. Indeed, converting ELVEY's total absorption (the unit of area is complete absorption over the with 1 Å) to my unit by first comparing ELVEY's measurements with Miss WILLIAMS' measurements and then using Fig. 9 of the present paper, we obtain the full drawn line of Fig. 24. The dotted line is the relation of Fig. 17. The agreement between the curves must be regarded as very satisfactory when we consider the uncertainty introduced by the intermediate steps. The relation found by ELVEY is thus seen to be identical with mine.

From the above, it is obvious that the *total hydrogen line absorption is connected to absolute magnitude both on the high-temperature side and on the low-temperature side of the hydrogen line maximum*. These effects are surely primarily »abundance effects«. Besides these effects there may, however, appear luminosity effects in the shape of the line contours, due to STARK broadening. In the measurement of the excess in line width it may be possible to derive a second approximation to the absolute magnitudes derived from the total absorption. This would, of course, be possible only when using high dispersion spectra.

It is a very happy circumstance if the colour does not enter the luminosity relations on the high temperature side, because the colour cannot be quite as accurately measured as the line absorption, and moreover a selective absorption in space would imperil the method to some degree.

The dependence between colour and luminosity in the top of Fig. 22 seems to be a relation of the same kind as that of the main series in the HERTZSPRUNG-RUSSELL diagram. The discontinuity in the luminosity diagram between the A stars of advanced colour and the F stars will be discussed in Chapter VIII.

CHAPTER VII.

Selective Absorption in Space.¹

The question whether the star light is subject to an absorption in space is one of the most puzzling problems of astronomy. Some data tell in favour of it, other data do not and a definite judgment on this point has not yet been possible.

We know there exists dark nebulae absorbing a part of the light of the stars situated beyond them and indeed we are sometimes able to determine exactly how much light is absorbed by such a dark nebula. But to determine the absorption in interstellar space in general is a much more difficult problem, because of the very small value of the absorption per unit distance in this case.

¹ I am indebted to Miss EMMA WILLIAMS and Dr. R. TRUMPLER for valuable correspondence on this subject.

An absorption in space may either be equal for all wavelengths or selective, which means that the absorption coefficient is a function of the wavelength. Such a selective absorption is generally attributed to a Rayleigh scattering of interstellar dust.

The results from globular clusters and extragalactic nebulae give very small values of the general absorption in space, indicating that if there exists an absorption in space it is confined mainly to the galactic system. Moreover, several data point out that the absorption can appear to a remarkable extent only near the galactic plane because otherwise we would not see any extragalactic objects at all. In the galactic regions, however, very few extragalactic nebulae are seen and the reason for this may be a general absorption in the galactic plane. LUNDMARK¹ has shown that the dark nebulae are situated mainly in regions of the sky where very few extragalactic objects are visible. Surely the absorption in the dark nebulae accounts to a certain degree for this phenomenon but it seems probable that also a more general absorption is present. A recent work of TRUMPLER² gives good confirmation of such a general absorption within a thin layer situated in the galactic plane. The absorption found by TRUMPLER for the photographic region in spectrum is 0.67 magnitudes per 1000 parsecs. This value agrees well with the value 0.50 recently found by SCHALÉN.³

The idea of an absorbing layer in the galactic plane is favoured by the dark band visible in some extragalactic nebulae seen edgewise. This is surely due to a layer of absorbing matter.

I have suggested above that several of the early B stars in my list may be affected by a reddening due to scattering in interstellar space. These stars are the most luminous ones and several of them are situated at considerable distances. Their advanced colour contradicts the high temperature indicated by the helium lines.

A recent paper of GERASIMOVIC⁴ deals with this discrepancy. He has found reason to believe that the low colour temperature sometimes observed is not due to a selective absorption by cosmic matter but is a real effect. The high excitation can not be due to a very low density in the stellar atmospheres because that leads to unreasonably small densities. Gerasimovic suggests the high temperature lines appear by »superexcitation» produced by an excess of radiation in the ultra-violet.

Though this explanation has much in its favour, I have found it interesting to try to find out whether the early B stars in my list give evidence of a space red-

¹ K. LUNDMARK, Studies of Angalactic Nebulae, Nova Acta Regiae Societatis Scientiarum Upsaliensis, Volumen Extra Ordinem Editum 1927. Medd. etc. Upsala, No. 30, 1927.

² R. J. TRUMPLER, Preliminary Results on the Distances, Dimensions and Space Distribution of Open Star Clusters, Lick Observatory Bull. No. 420, 1930.

³ C. SCHALÉN, Zur Frage einer allgemeinen Absorption des Lichtes in Weltraum, Astr. Nachr. B. 236, p. 249, 1929. Medd. etc. Upsala, No. 45, 1929.

⁴ B. P. GERASIMOVIC, Harvard Circular 339, 1920.

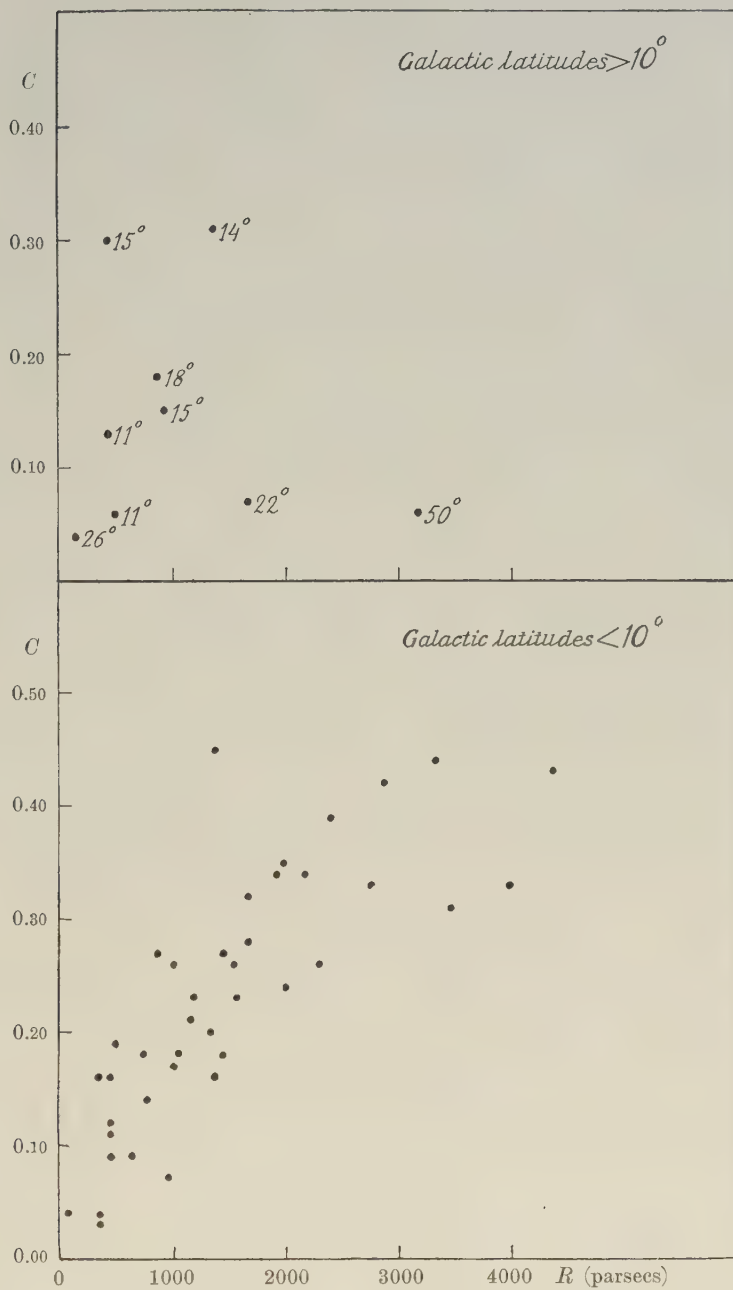


Fig. 25. The colour-equivalent C as function of stellar distance in parsecs for early B stars. The upper diagrams includes stars with galactic latitudes $> +10^\circ$, the lower one stars between $+2^\circ$ and $+10^\circ$ galactic latitude.

dening, because only from an inspection of the apparent magnitudes was this apparent.

To test this question I grouped the B 0—B 5 stars according to galactic latitude and separated the stars with a latitude $< 10^\circ$ from stars more distant from the galactic plane. The linear distances of the stars were calculated from the absolute magnitudes determined from Fig. 22, using the total line absorption of $H\gamma$ and $H\delta$. The colour was then plotted against these distances and Fig. 25 shows the result. The upper diagram includes stars situated at angular distances greater than 10° from the galactic plane. Here no definite correlation between colour and distance is seen but the stars are very few. The lower diagram, however, obtained for stars close to the galactic plane, shows a remarkably good correlation. Indeed, here no white stars at all are placed at great distances.

The relation can hardly be caused by mere chance or by systematic errors. One could think of a »magnitude-equation» in the colour-equivalent and I have tested this question by investigating other spectral types. Only the most luminous B 8—A 0 stars show a dependence between colour and apparent magnitude similar to that shown by the B stars, and it is thus obvious that the effect cannot be produced by systematic errors in the colour determinations. A systematic error could appear if the yellowish B stars are more luminous than the whitish ones as indicated in Chapter VI. This would make the absorption come out smaller but probably this effect is rather slight.

Fig. 25 may thus be regarded as good evidence of a selective absorption in the galactic plane.¹ But, if this is true the apparent magnitudes used for the calculation of the distances must need a correction. The distances (r') have been calculated from the photographic absolute magnitudes (M) and apparent photographic magnitudes (m) according to the well known formula

$$5 \log r' = m - M + 5. \quad (\text{VII: } 1)$$

If the absorption in space is uniform and equal to k magnitudes per parsec the true distance r is obtained from r' by means of

$$5 \log r' = 5 \log r + kr. \quad (\text{VII: } 2)$$

Trumpler has found $k = 0.00067$ for the photographic region. I have adopted this value and converted r' to r graphically. Fig. 26 shows the result. The curved relation of Fig. 25 has by this process become almost linear and the scattering of the points is now seen to be much less.

The line drawn in Fig. 26 gives the absorption *0.19 magnitudes per 1000 parsecs* for $\lambda 3912$ relative to $\lambda 4415$. This value may be considered in good agreement with TRUMPLER's value 0.32 between the wavelengths $\lambda 4300$ and $\lambda 5600$. Assuming

¹ The stars are situated between 74° and 105° galactic longitude.

RAYLEIGH'S law to be valid I have transformed TRUMPLER'S value to my interval in wavelength and found the value 0.27. If our determinations were quite correct this would indicate that the absorption does not increase as rapidly with decreasing wavelength $1/\lambda^4$. Though this result might explain why the intensity of early B

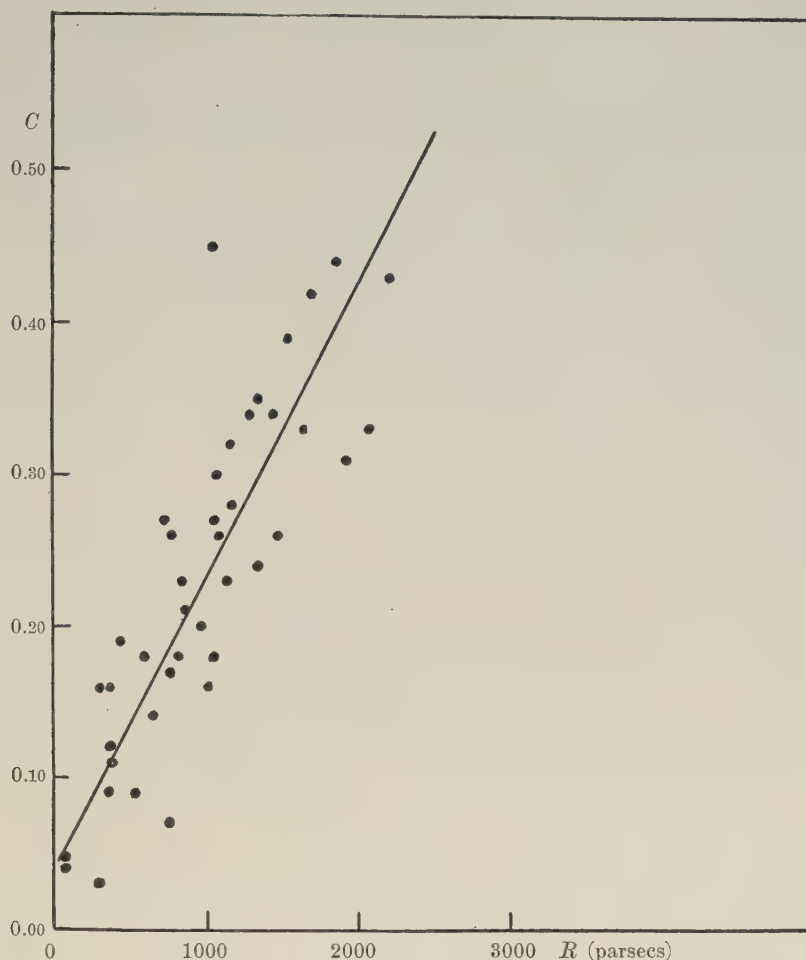


Fig. 26. The relationship of the lower diagram in Fig. 25 when corrected for a photographic absorption of 0.67 magnitudes per 1000 parsecs.

stars in the ultraviolet is so remarkably high¹ we are not entitled to draw such a conclusion from the present data which of course is too uncertain.

The results from the present investigation speak in favour of a selective absorption in space produced by a thin layer situated in the galactic plane. The advanced

¹ Compare GERASIMOVIC, loc. cit.

colour of most of my early B stars seems to be due to this cause. Some exceptions occur, however, indicating that the advanced colour sometimes may be attributed to the stars themselves or be caused by absorption in local clouds.

CHAPTER VIII.

A Suggested Break in the Spectral Sequence between A and F Type Stars.

With the recent development of astrophysics the well known spectral sequence O, B, A, F, G, K, M, has been well established as a uniform temperature series. The interpretation of this sequence, however, is complete only when we also consider another quantity, the absolute luminosity of the stars. The famous relationship known as the HERTZSPRUNG-RUSSELL diagram gives the distribution of stars with regard to luminosity and spectral type. In this diagram we distinguish the main series proceeding from the luminous B stars to the faint M dwarfs, the yellowish and reddish giants, and finally the white dwarfs.

The main series in this diagram has hitherto been regarded as quite smooth. Some results from the present investigation, however, give evidence of a less smooth transition between the A and F types than has so far been assumed.

The break between these types is noticeable in colour, star density, luminosity, and the distribution of velocities. The spectral types, which are based on the relative intensities of the more prominent spectral lines, define a temperature scale which sometimes deviates from that corresponding to the colour of the stars. In the foregoing chapter we found this was the case for the early B stars. A similar deviation occurs in some of the A type stars, though the cause here is not the same.

The colour excess of the A type stars may be seen in the relationship between colour and spectral type. Such a comparison was given in Chapter V and it was remarked there that the same colour excess comes to view in several similar comparisons made by other authors.

The effect is also seen in Figs. 12 and 13 of Chapter VI which give the relationship between total hydrogen absorption and colour. Several A 3—A 5 stars show here a more advanced colour than the early F stars. The distinction of two branches is striking when regarding the star density. Remarkably few stars are situated in the top of the F branch (i.e. in the region of high luminosity). This is a very interesting fact and is perhaps worth remembering in connection with hypotheses on the evolution of stars.

That the discontinuity in colour corresponds to a shift in luminosity has been shown in Fig. 22. If this effect is real, of course, it must be seen also in the



Fig. 27. Relation of absolute magnitude to spectral class according to LINDBLAD.

ordinary HERTZSPRUNG-RUSSELL diagram. In Fig. 27 I have given such a diagram constructed by LINDBLAD.¹ The F—M stars in this diagram have been taken from the Mount Wilson catalogue of 1646 stars, the A stars are members of the Pleiades, Hyades, Praesepe and Ursa Major group, and the B stars, finally, are plotted from KAPTEYN's work on B stars in the southern celestial hemisphere.

This HERTZSPRUNG-RUSSELL diagram gives a very good confirmation of the discontinuity proposed above. The A stars are split up in two branches, one

¹ B. LINDBLAD, De spektroskopiska metoderna för bestämning av stjärnornas avstånd, Populär Astronomisk Tidskrift, p. 33, 1922.

continuously proceeding into the F stars and one showing a stronger slope and ending with type A 5. There can hardly be any doubt as to the identity of this effect with the one proposed by me and indeed the effect may also be seen in HERTZSPRUNG-RUSSELL diagrams derived from other stars. The diagram for visual double stars given by BRILL¹ shows the effect very clearly.

We return to Fig. 22. It seems from the above that the horizontal luminosity line $+1.0$ situated in the top of the F branch², may be connected with the $+1.0$ area in the top of the high-temperature branch to the left. From the point at about $H\gamma = 0.70$, $C = 0.15$ in Fig. 22 the spectral sequence seems to be split up in two branches; one forming the ordinary main series (horizontal luminosity lines) and one forming the coloured A type group (vertical luminosity lines). It is not impossible that the famous white dwarfs form the end of the coloured A type series, but this question cannot be settled at present.

It is interesting in this connection to pay attention to the question of the magnitude-spectral class diagrams for stellar clusters. Do these show such a discontinuity as the one in question? As already mentioned, LINDBLAD's HERTZSPRUNG-RUSSELL diagram was based on clusters as regards A type stars. Some clusters may thus obviously show the discontinuity. This is very striking in the case of the Pleiades, as may be seen in the diagrams of TRUMPLER³ and SCHWASSMANN.⁴ In a private communication Dr. TRUMPLER has suggested to me that the faint A stars in the Pleiades in reality are F stars which have been classified too early. When using slit spectra these stars show metallic lines which indicate a later spectral type than that given by the hydrogen lines and the K line. Though this explanation is of great interest I think it cannot account for the strong hydrogen line intensity of the yellowish A type stars. I thus prefer to call these stars A type stars.

It has been mentioned above⁵ that the discontinuity between the A stars and F stars comes to view in not only colour and luminosity but also in the velocity distribution of the stars. The difference in motion may possibly be attributed to a difference in mass. One could also suppose that the different types really have different origin, and thus draw analogies with star clusters. I have wondered whether TRUMPLER's type⁶ 1 b may be identical with the B and A stars ending with the yellowish A group, and whether the type 1 a may be identical with the main series beginning with the early F stars. At present it does not seem possible to

¹ A. BRILL, Strahlungsenergetische Parallaxen von 123 visuellen Doppelsternen, Veröff. der Universitätssternwarte zu Berlin-Babelsberg, Band VII, Heft 1, 1927.

² When using the term »F branch» I do not include stars of supergiant character, which according to Chapter VI do not show the same relationship between hydrogen line intensity and luminosity as ordinary F. stars.

³ R. TRUMPLER, The Physical Members of the Pleiades Group. Lick Bull 333, 1921.

⁴ A. SCHWASSMANN, Mitteilungen der Hamburger Sternwarte in Bergedorf. B. 6. No. 31, 1930.

⁵ Compare page 56.

⁶ R. J. TRUMPLER, Spectral Types in Open Clusters, Publ. Ast. Soc. Pacific. 37, p. 307, 1925.

pass a definite judgement on this point, but it is obvious that the two kinds of stars appear together in some clusters. Of course, a rigorous treatment of this subject would require exact line photometry.

The yellowish A type stars show remarkably strong hydrogen lines and a faint K line, considering the low luminosity and temperature of these stars. Probably the low colour temperature is to some extent due to a depression of the radiation curve in the violet because the effect is more pronounced for some colour equivalents than for others. The presence of abnormally strong metallic lines in these A type stars argues in favour of a true temperature effect but this is not quite certain. It seems to me that these stars furnish an example of the »Adams-Russell phenomenon», i.e. a departure from thermodynamic equilibrium in the stellar atmospheres. It is interesting in this connection to pay attention to the works of UNSÖLD¹ and EDDINGTON² on this subject.

CHAPTER IX.

The Relationship between $H\gamma$ and $H\delta$.

As the two lines $H\gamma$ and $H\delta$ belong to the same spectral series, it is quite natural that a very intimate relation must exist between their intensities in stellar spectra. In my work of 1927 I showed that this is also the case but at the same time it was found that the relative intensities of these lines come out differently for stars of different colour. In order to get further evidence on this point I have studied the relationship between these lines from the present material.

Fig. 28 shows the relationship for the luminous B and A stars, i.e. all B0—A0 stars with $H\gamma < 0.50$ and those of the other B and A stars for which the colour is low ($C < 0.25$). As is seen from this figure, the relationship is almost linear and the points are situated remarkably close to a smooth curve. The intensity of $H\delta$ appears greater than that of $H\gamma$ but this effect is caused primarily by the method of measuring the lines. The prismatic scale makes the diaphragm cut out a more narrow region of $H\delta$ (19 Å) than of $H\gamma$ (23 Å). According to Miss WILLIAMS³ the total absorption of these lines (frequency units) is very nearly the same, or perhaps a little stronger for $H\gamma$.

Fig. 29 gives the corresponding diagram for A stars of advanced colour ($C \geq 0.25$) and for F stars. The relationship of Fig. 28 is here given by the dotted line.

¹ A. UNSÖLD, Über Abweichungen der Sternatmosphären vom thermischen Gleichgewicht, Zeitschrift für Astrophysik, Band 1, p. 1, 1930.

² H. N. RUSSELL, On the Composition of the Sun's Atmosphere, Astroph. Journal 70, p. 74, 1929.

³ EMMA T. R. WILLIAMS, Harvard Circular 348, 1929.

Also these stars follow very closely a straight line but as a rule $H\delta$ is not as strong compared with $H\gamma$ as in the case of the high temperature stars in Fig. 28. The effect is not so marked as in my previous paper, but there is no doubt as to its reality.¹

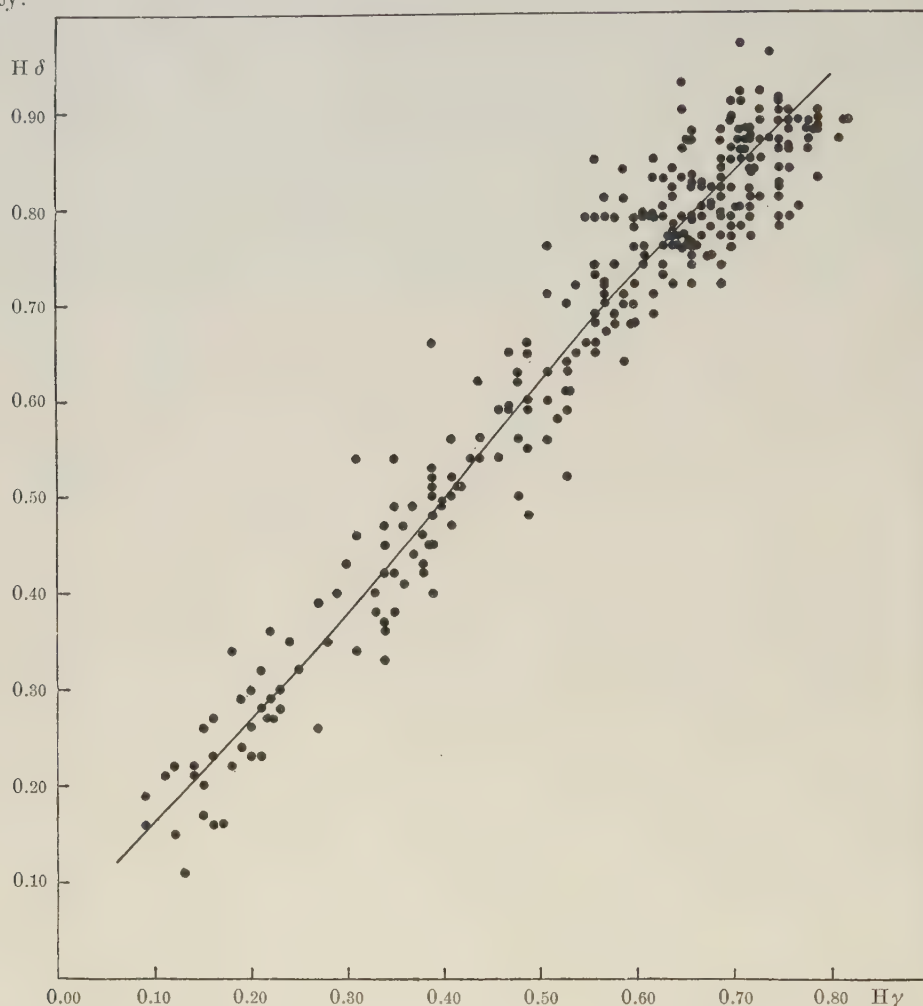


Fig. 28. The intensity relationship between $H\delta$ and $H\gamma$ for stars situated on the high temperature side of the BALMER line maximum. B 0—A 0 stars with $H\gamma < 0.50$ and other B and A stars with low colour ($C < 0.25$)

What may now be the cause of this change in the relative intensity of $H\gamma$ and $H\delta$? Is the effect attributed to the total absorption in the hydrogen lines, is it a consequence of a shift in the shape of the line contours combined with the effect of prismatic scale, or is it caused by other spectral lines situated within the wings of the hydrogen lines?

¹ Most F 0 [A 2] stars show $H\delta$ remarkably faint. Compare page 79.

We know that the shape of the hydrogen line contours alters systematically when proceeding from the B stars to the F stars. As a more narrow part of $H\delta$ is measured than of $H\gamma$, a change in the shape of the contours may possibly cause a change in the relative line intensity. I have tested this question by measuring

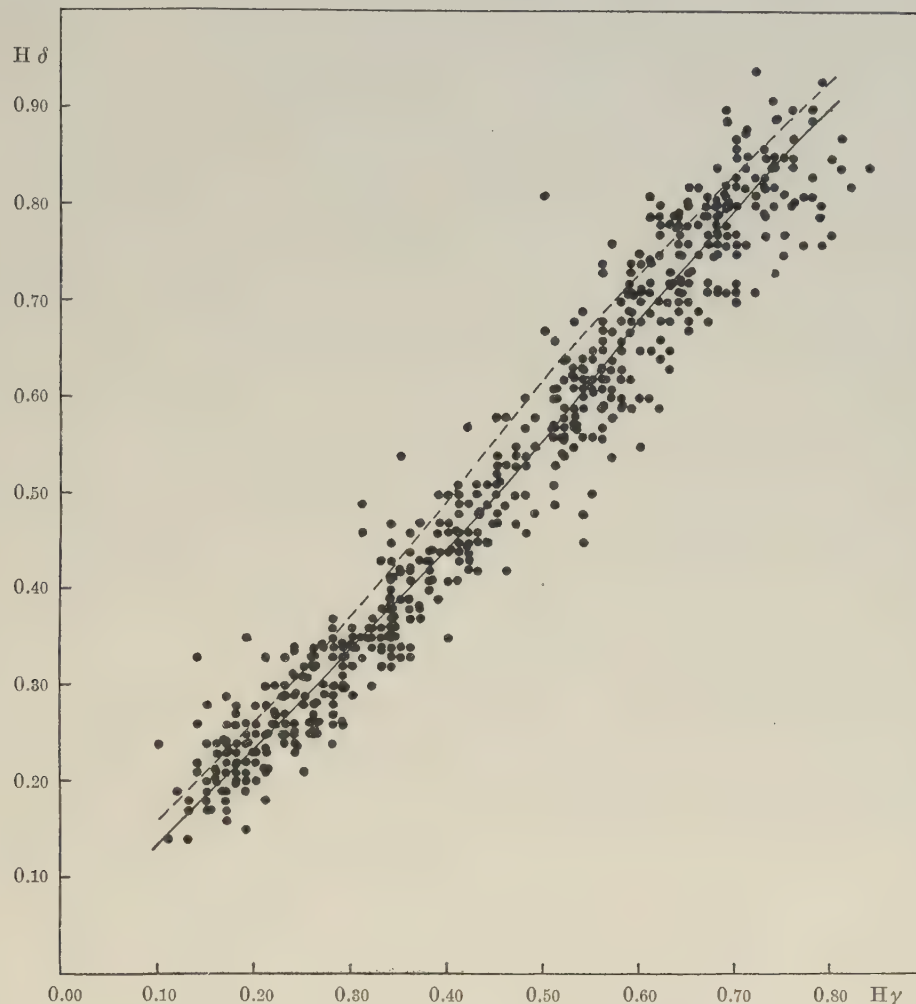


Fig. 29. The intensity relationship between $H\delta$ and $H\gamma$ for stars situated on the low temperature side of the BALMER line maximum. The relation of Fig. 28 is given by dotted line.

$H\delta$ with another diaphragm cutting out the same interval in wavelength as the ordinary diaphragm does in the case of $H\gamma$. Comparing the two kinds of measures of $H\delta$ for a number of stars, I found almost exactly the same relationship for the high temperature stars as for the low temperature stars, which shows that the effect above cannot be caused by a combination of prismatic scale and a systematic change in the contours when we proceed to low temperatures.

Such an effect as the one in question might be due to other spectral lines situated within the wings of the hydrogen lines. An inspection of some high dispersion spectra taken at Cambridge has shown that this can not be the case for B and A stars. The Si^{+++} lines $\lambda 4089$ and $\lambda 4116$ which may seem dangerous in the measurement of $\text{H}\delta$ in early B stars are situated outside the region analysed by the photometer. In the case of the F stars $\text{H}\gamma$ may be somewhat increased by some lines due to Fe, Cr and Ti^+ between $\lambda 4337$ and $\lambda 4345$, but at the same time $\text{H}\delta$ is a little increased by some other lines due to Fe and Ca between $\lambda 4095$ and $\lambda 4099$ and it seems that the resulting influence of these faint lines can hardly account for the observed intensity effect, at least in A type stars. Also the regions defining the continuous background do not seem to be noticeably influenced by line absorption.

We are thus led to the conclusion that the observed shift in the relative intensity of the lines $\text{H}\gamma$ and $\text{H}\delta$ when proceeding from high temperature stars to low temperature stars is primarily a change in the total absorption of these lines, i.e. $\text{H}\delta$ decreases more rapidly with decreasing temperature than $\text{H}\gamma$. The same effect is present in Miss WILLIAMS' measurements though not so very marked, but the number of low temperature stars in her list is rather small.

In my previous work (1927) I suggested that the change in the relative intensity of $\text{H}\gamma$ and $\text{H}\delta$ is related to the pressure in the stellar atmospheres and probably connected with the effect found by Miss PAYNE and Miss HOWE concerning the influence of luminosity on the number of BALMER lines observed.¹ The effect is probably also connected to the phenomenon of bright lines in some early type stars. If BALMER lines appear in emission, $\text{H}\alpha$ is always brightest and successive lines grow fainter and pass over into absorption lines.² It is not out of the question that the effect is also correlated to the STARK broadening which increases with the principal quantum number, and accordingly may affect $\text{H}\delta$ more than $\text{H}\gamma$.

The break suggested in Chapter VIII is visible in Fig. 29 as a minimum in the star density at about $\text{H}\delta = 0.54$, $\text{H}\gamma = 0.49$.

CHAPTER X

The *K*-Line.

It has been mentioned before that the present work deals not only with measurements of hydrogen lines and colour but also with the *K*-line. The measurements of this line are not quite as accurate as in the case of $\text{H}\gamma$ and $\text{H}\delta$ ³ but good enough to allow some interesting statistics.

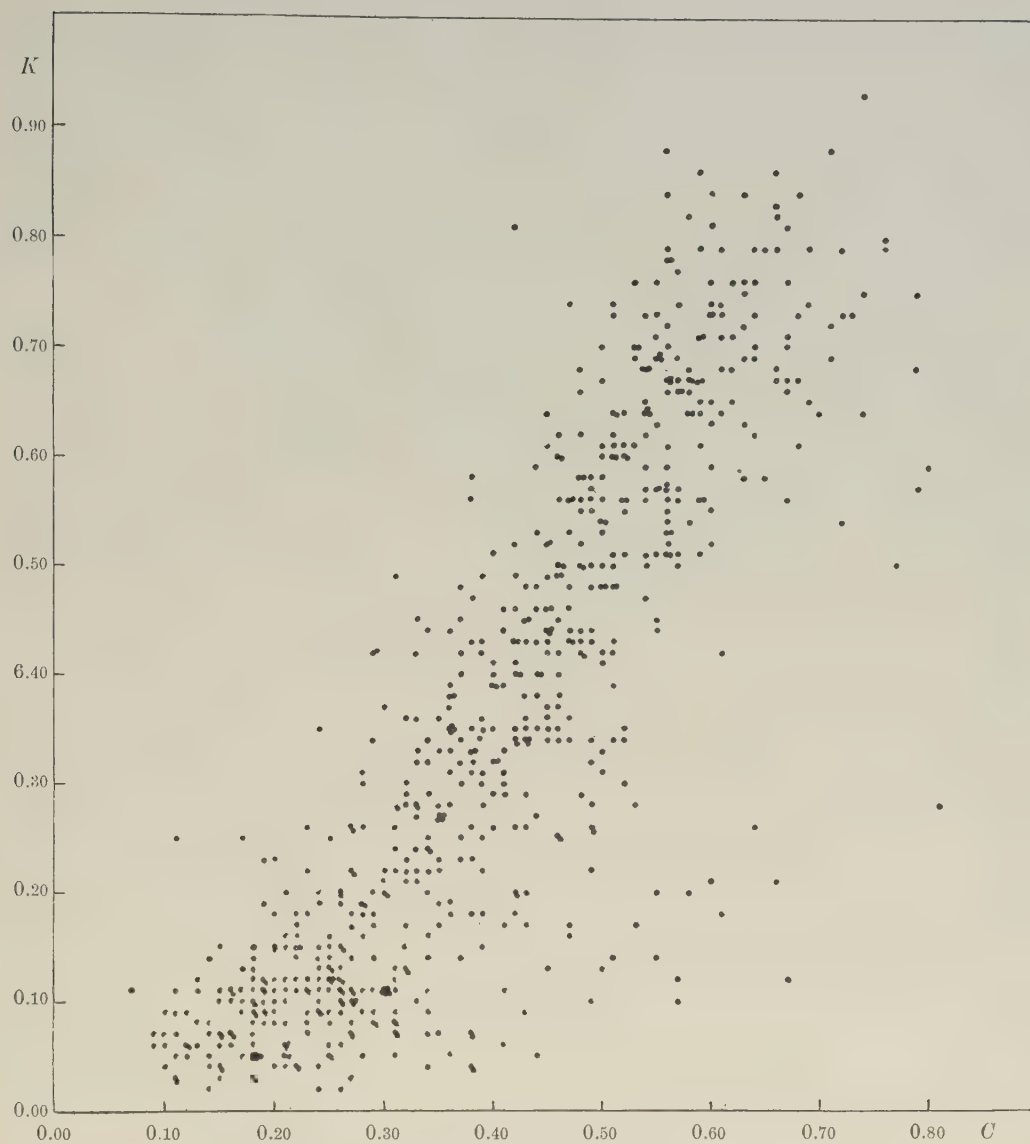
The *K*-line is one of the most important lines characterizing stellar spectra. It is generally considered a very good measure of temperature⁴, at least in A type

¹ Harvard Circular 287, 1925.

² I owe this remark to discussions with Professor STRATTON at Cambridge.

³ Compare page 35.

⁴ See EMMA T. R. WILLIAMS, Harvard Circular 348, 1929.

Fig. 30. Intensity of K as a function of colour (C).

stars where this line according to MILNE¹ is almost completely insensitive for changes in luminosity. That the K -line furnishes no criterion of luminosity for A type stars has been proved in the present investigation for stars of maximum hydrogen line intensity (groups IX—XIII in Fig. 14). When the colour is kept constant the

¹ E. A. MILNE, A »Null-effect» in the Theory of the Influence of Absolute Magnitude on Stellar Spectra. Harvard Bull. 870, 1929.

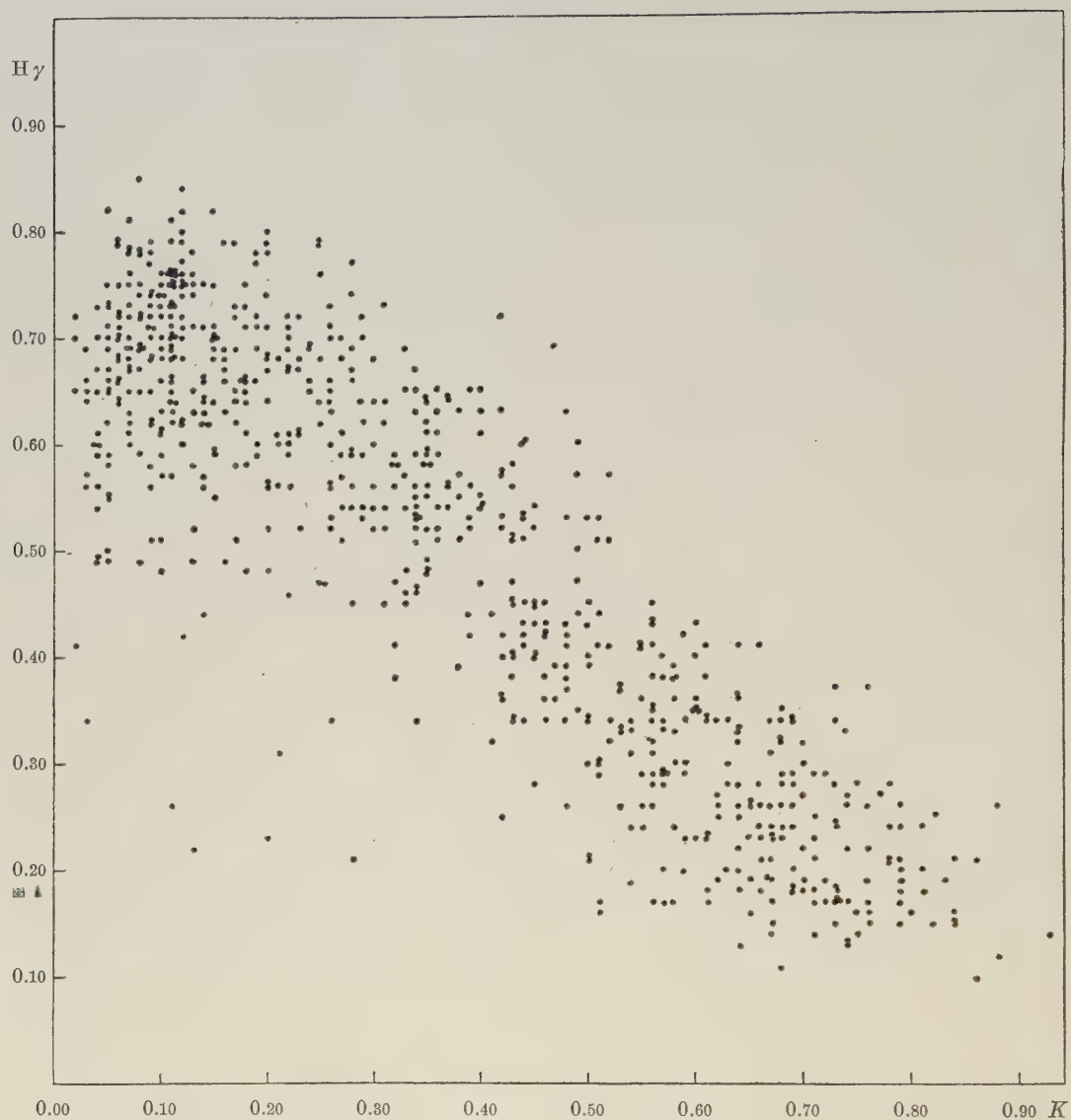


Fig. 31. The relationship between intensity of $H\gamma$ and intensity of K

average proper motion does not show any trend with increasing intensity of the K -line, a result which thus confirms the »null-effect» predicted by MILNE.

Some evidence about the K -line as a measure of temperature may be obtained from a comparison between the intensity of the K -line and the colour-equivalent C . Fig. 30 shows such a comparison for the stars in the Greenwich zone.

Obviously there is a pronounced correlation between K and C , though the correlation is not so high as might have been expected from theory. The rela-

tionship is better, however, as that given in my previous work (1927). The scattering of the points in Fig. 30 may be due to some extent to accidental errors¹ but these cannot account for the total scattering of the points. That some A 0 stars show a remarkably high colour may in fact be noticed when inspecting the plates with the naked eye. The strong deviation of some stars from the general run in the right-hand part of the figure is very striking. Here we have some stars showing the *K*-line abnormally faint with respect to their very advanced colour. Such stars have also been noticed by LINDBLAD who designs them F 0 [A 2] or similarly. As a rule, their reduced proper motions indicate faint luminosities, and probably they belong to the coloured A type branch suggested in Chapter VIII. Some of these stars, however, are possibly double stars.²

The main branch in Fig. 30 shows a faint but characteristic shift in its slope at about $K = 0.26$, $C = 0.35$. Probably this shift is connected with the discontinuity treated in the foregoing chapter.

The comparison between the *K*-line and the colour equivalent *C* has thus shown that the intensity of the *K*-line, on the whole, may be regarded as a good measure of temperature, though it is not always so very significant.

It is interesting in this connection to compare the intensity of the hydrogen lines with that of the *K*-line. It has been found in Figs. 12 and 13 that the correlation between hydrogen line intensity and colour is rather close for F type stars. On page 59, however, it has been pointed out that probably this is not primarily a consequence of a close dependence between hydrogen line intensity and temperature but is caused by an intimate relation between hydrogen line intensity and luminosity combined with the phenomenon of the main series in the HERTZSPRUNG-RUSSELL diagram.

The relationship between $H\gamma$ (not mean of $H\gamma$ and reduced $H\delta$) and *K* is given in Fig. 31. The correlation between these quantities may not be regarded better than that between *K* and *C*. As $H\gamma$ is more accurately measured than *C* this result points out that $H\gamma$ cannot be considered a better measure of temperature than *C* for F type stars. Also in Fig. 31 we can see a faint indication of the break suggested in Chapter VIII.

Introduction to the Catalogues.³

Catalogue I. Stars in the Greenwich polar zone.

Catalogue I contains the main part of stars studied in the present investigation, i.e. 882 stars in the Greenwich zone between $+65^\circ$ and $+70^\circ$ declination

¹ It is worth remembering here that the relationship between *K* and *C* has been used to derive corrections for varying plate sensitivity and atmospheric transmission (see page 37). This process, however, would rather tend to make Fig. 30 look a little better than the true relationship.

² The fact that most F 0 [A 2] stars show $H\delta$ abnormally faint does not argue in favour of mixed spectra. Compare Figs. 12 and 13 and page 74.

³ A list of some bright F type stars is given in Table XII, page 58.

with the exception of the part between $8^h 30^m$ and $13^h 30^m$ right ascension which has been studied earlier by LINDBLAD according to the classification methods.

The three first columns in Catalogue I contain B.D. number and coordinates for 1900. Then I have given the Greenwich photographic magnitude corrected to the International Scale by applying the corrections of Harvard Annals 71, p. 224 and Harvard Bulletin 781. The spectral types in the fifth column are classified chiefly by using LINDBLAD's scheme.¹ I have tried to divide also the early B stars into subtypes because the spectra were sharp enough to show distinctly some of the He lines, and in some cases also He^+ and Si^{+++} lines could be noticed. My spectral types agree on the whole very well with the Harvard types in the sixth column. In the columns 7–10 I have given the determined total line absorption in $\text{H}\gamma$, $\text{H}\delta$ and K and furthermore the colour-equivalent C .² The quantity n in the eleventh column denotes the number of images measured. The numbers sometimes given in parenthesis denote the number of images measured to determine the colour-equivalent C if the determination of this quantity was based on more images than those of the lines. This was the case for the secondary standard regions. In the last column, finally, is the absolute photographic magnitude determined from $\text{H}\gamma$, $\text{H}\delta$ and C by using Fig. 22.

Catalogue II. Stars in the Pleiades.

Catalogue II contains 43 stars in the Pleiades group. The line intensities and colour measured for the faintest stars in this list have been taken from Medd. Astr. Observ. Upsala No. 33 merely by correcting the values given there to the new grating magnitude constant. For the brighter stars, however, new data have been available from different test plates taken for the present work. The columns in Catalogue II are analogous to those in Catalogue I. The first column gives the catalogue number in TRUMPLER's list of physical members of the Pleiades group (Lick Bull. 333). Professor HERTZSPRUNG has kindly communicated to me those stars which are situated in the region investigated at Leiden and show the same proper motion as Alcyone. They are denoted by an asterisk after the TRUMPLER number. The star TRUMPLER 742 does not seem to be physical member of the Pleiades group according to HERTZSPRUNG.

The spectral types given in the fourth column are determined by LINDBLAD and SCHALÉN (Compare Medd. etc. No. 33). The photographic magnitude is taken from TRUMPLER's catalogue. In the last column is given the number of spectra measured. When two numbers are given the first one refers to the hydrogen lines and the second one to the colour-equivalent C .

¹ B. LINDBLAD, Medd. Astr. Observ. Upsala No. 11, 1926.

² A colon after a figure denotes that the determination is uncertain.

Catalogue I.
Stars in the Greenwich polar zone.

B.D.	α (1900)	δ (1900)	m_{ph}	Sp. U.	Sp. H.	H γ	H δ	K	C	n	M_{ph}
64° 5	0 ^h 5 ^m	+65°.2	7.9	A 0	A 0	0.76	0.89		0.17	1	+1.0
36	0 18	64.8	8.5	F 2	F 0	0.30	0.34	0.50	0.57	2 (5)	+3.0
44	0 20	64.8	7.7	B 8	B 9	0.39	0.50		0.28	2 (5)	-0.6
52	0 25	64.7	8.7	B 5	B	0.14	0.21		0.33	2 (3)	-3.4
66	0 33	64.9	9.2	B 8	A 0	0.72	0.85		0.24	1	+1.3
75	0 39	64.8	8.4	A 0	A 0	0.70	0.85		0.25	1	+1.4
83	0 43	65.0	9.0	B 0	F 5	0.12	0.15		0.33	1	-3.9
84	0 44	64.5	8.2	A 3	A 5	0.55	0.56	0.34	0.51	1	+2.5
107	0 52	64.9	8.6	A 0	A 0	0.75	0.81	0.12	0.21	1	+1.1
109	0 54	64.6	8.5	B 8	B 9	0.48	0.50		0.23	2	-0.2
127	1 5	64.5	var.	B 8	B 8	0.56	0.68		0.13	5	+0.5
130	1 7	65.1	9.2	B 8	A 0	0.57	0.73		0.31	1	+1.9
196	1 29	64.8	8.5	A 0	A 2	0.80	0.77	0.20	0.30	1	+1.8
268	1 50	64.9	8.0	B 8	B 3	0.23	0.28		0.34	1	-2.5
282	1 55	64.4	5.8	A 0	A 2	0.70	0.85	0.06	0.10	3	+1.0
285	1 57	64.6	6.5	A 0	A 0	0.69	0.79		0.19	1 (3)	+1.0
295	2 1	64.5	7.6	B 3	B 3	0.12	0.22		0.28	1	-3.4
313	2 10	64.8	7.9	F 8	F 8	0.13	0.18	0.74	0.69	1	+4.3
314	2 10	65.1	7.9	F 8	F 8	0.19	0.20	0.67	0.67	2	+4.4
321	2 15	64.8	7.7	F 8	F 8	0.13	0.14	0.64	0.74	1	+5.0
327	2 20	65.0	8.5	A 0	A 0	0.72	0.80	0.02	0.24	1	+1.3
337	2 30	64.9	8.3	A 0	B 8	0.56	0.62	0.04	0.33	1 (2)	+2.5
338	2 30	64.9	8.0	F 8	F 8	0.11	0.14	0.68	0.79	1 (2)	+5.1
356	2 50	64.7	8.4	A 3	A 2	0.50	0.67	0.49	0.45	1 (2)	+2.5
365	2 57	65.2	8.5	F 8	F 8	0.15	0.17	0.73	0.73	1 (2)	+4.3
367	2 57	65.1	8.2	A 3	A 5	0.54	0.59	0.28	0.35	2 (3)	+2.2
375	3 2	64.5	6.5	A 2	A 5	0.61	0.69	0.18	0.33	3 (5)	+2.5
376	3 4	64.7	7.3	A 5	F 0	0.45	0.47	0.31	0.41	2 (3)	
378	3 7	64.5	8.2	F 5	F 8	0.17	0.21	0.73	0.60	1 (2)	+4.5
383	3 10	64.5	8.4	B 8	B 9	0.41	0.52		0.22	1 (2)	-0.5
388	3 14	64.8	8.8	A 0	A 0	0.65	0.80	0.05	0.28	1 (2)	+1.7
398	3 28	65.0	8.3	F 8	F 8	0.18	0.23	0.79	0.66	2	+4.3
408	3 40	64.4	8.0	F 5	F 5	0.26	0.25	0.65	0.60	2	+3.3

Cont.

B.D.	α (1900)	δ (1900)	m_{ph}	Sp. U.	Sp. H.	H γ	H δ	K	C	n	M_{ph}
64° 412	3 ^h 45 ^m	64° 4	8.2	F5	F8	0.17	0.24	0.51	0.55	1	+4.3
414	3 47	65.1	8.2	A3	A3	0.59	0.59	0.35	0.40	1	+2.5
424	3 57	64.7	8.2	A2	A3	0.65	0.67	0.26	0.49	1	+2.5
429	4 3	64.7	8.2	F0	F0	0.41	0.46	0.44	0.41	1	+1.5
434	4 11	64.6	8.8	F2	F5	0.34	0.34	0.73	0.60	1	+2.8
449	4 21	64.8	7.8	F2	F0	0.37	0.47	0.53	0.56	2	+1.7
457	4 24	64.8	7.8	F5	F5	0.23	0.25	0.67	0.68	2	+4.0
468	4 29	64.7	8.6	F0	F2	0.28	0.35	0.56	0.47	1	+3.2
470	4 32	64.9	8.8	A0	A0	0.49	0.58	0.05	0.25	1	0.0
473	4 35	64.9	9.0	A2	A2	0.68	0.75	0.11	0.31	1	+1.9
500	5 0	64.8	6.7	F5	F2	0.28	0.34	0.64	0.59	2	+3.2
504	5 3	64.6	8.6	F5	F5	0.21	0.23	0.67	0.57	1	+4.2
506	5 6	64.5	8.9	A0	A0	0.56	0.79	0.03	0.18	1	+0.8
516	5 9	64.7	9.0	A2	A0	0.64	0.79	0.20	0.42	1	+2.5
523	5 15	64.6	8.3	F8	F8	0.23	0.29	0.59	0.80	1	
534	5 25	64.9	7.2	A0	A2	0.59	0.81	0.10	0.24	1 (2)	+1.3
542	5 34	64.7	8.7	F0	F0	0.38	0.43	0.43	0.49	2 (3)	+1.9
551	5 44	64.9	8.7	A3	A5	0.59	0.71	0.32	0.40	1	+2.5
580	6 14	64.9	8.6	F2	F5	0.26	0.34	0.55	0.56	2	+3.3
587	6 21	64.5	8.8	F2	F8	0.34	0.33	0.43	0.39	1	+2.8
593	6 29	64.8	8.0	F5	F5	0.23	0.33	0.61	0.68	1	+3.5
597	6 30	64.7	9.1	A0	A0	0.72	0.94	0.11	0.29	1	+1.8
616	6 57	64.5	8.7	F5	F5	0.21	0.21	0.50	0.49	2	+4.3
618	6 59	64.5	8.4	A0	A0	0.77	0.80	0.09	0.12	2	+1.0
632	7 19	64.8	9.1	A5	A5	0.41	0.51	0.51	0.51	2	+1.1
651	7 40	64.6	8.2	F2	F2	0.36	0.37	0.46	0.47	2	+2.5
1043	15 4	64.8	8.4	B8	A0	0.64	0.84		0.20	2	+1.0
1222	17 48	64.8	7.3	A0	A0	0.84	0.84	0.12	0.25	1 (2)	+1.4
1252	18 13	64.4	5.5	F2	F2	0.29	0.30	0.51	0.57	1	+3.3
1415	20 6	64.9	7.7	A3	A5	0.62	0.64	0.35	0.45	1	+2.5
1417	20 7	64.9	8.2	A5	A5	0.51	0.49	0.38	0.44	1	
1450	20 32	64.3	8.9	F2	F2	0.26	0.25	0.53	0.47	1	+3.8
1451	20 33	64.4	8.6	A0	A0	0.69	0.72	0.15	0.20	1	+0.9
1457	20 38	64.8	8.6	A0	B8	0.66	0.69	0.18	0.39	1 (2)	+2.5
1470	20 48	64.2	8.8	A5	A3	0.52	0.53	0.39		1	
1487	20 57	64.9	8.8	A3	A5	0.61	0.60	0.36	0.32	1	+2.0
1496	21 3	64.6	8.3	A0	A0	0.74	0.82	0.10	0.27	2 (3)	+1.6
1527	21 17	64.4	5.0	B0	B3 <i>p</i>	0.17	0.16		0.06	3	-3.5

Cont.

B.D.	α (1900)	δ (1900)	m_{ph}	Sp. U.	Sp. H.	H γ	H δ	K	C	n	M_{ph}
64° 1535	21 ^h 21 ^m	64° .6	7.5	B8	B9	0.67	0.79		0.11	1 (2)	+1.0
1536	21 21	64.6	7.2	B8	B9	0.75	0.78		0.12	1 (2)	+1.0
1538	21 21	64.5	8.3	A0	B9	0.56	0.66		0.20	1 (2)	+0.5
1546	21 24	64.8	8.3	F5	F8	0.26	0.27	0.48:	0.70	1	+3.6
1564	21 30	65.1	8.6	A0	A0	0.74	0.89	0.08	0.31	2	+1.9
1569	21 33	65.1	7.8	A0	A0	0.63	0.73	0.10	0.21	3	+1.1
1604	21 52	64.5	8.2	A0	A0	0.68	0.82	0.04	0.20	2	+1.0
1606	21 53	65.2	8.8	B8	A	0.66	0.76		0.16	1	+0.9
1607	21 53	64.8	5.6	B3	B2	0.22	0.29		0.12	3	-2.5
1611	21 54	65.1	7.3	B5	B3	0.34	0.33		0.09	1	-1.6
1617	21 59	65.0	8.4	A0	A0	0.70	0.78	0.07	0.18	1	+1.0
1633	22 7	64.5	8.9	A2	A0	0.79	0.88	0.20	0.21	1	+1.1
1634	22 8	65.0	7.6	A0	A0	0.75	0.89	0.07	0.15	2	+1.0
1645	22 16	65.1	8.9	A3	A2	0.52	0.54	0.30	0.52	2	
1646	22 16	64.3	7.6	A5	A5	0.45	0.51	0.44	0.34	2	
1649	22 18	64.8	8.0	A3	A2	0.47	0.54	0.25	0.46	3	
1662	22 23	65.0	8.2	A2	A3	0.52	0.64	0.23	0.35	3	+2.2
1664	22 24	64.6	5.6	B0	B0	0.13	0.11		0.27	4	-4.1
1672	22 26	64.6	8.3	B5	B0	0.16	0.23		0.24	3	-3.2
1677	22 28	64.9	9.3	B8	—	0.23:	0.30:		0.38:	1	-2.4
1682	22 31	64.7	7.8	B8	B9	0.64	0.77		0.18	1	+0.9
1698	22 37	64.7	8.6	B5	B3	0.20	0.30		0.32	1	-2.5
1699	22 37	64.7	8.9	B5	—	0.21	0.23		0.26	1	-2.9
1702	22 39	65.2	8.0	A0	A0	0.76	0.90	0.11	0.22	1	+1.2
1704	22 40	64.8	6.6	B3	B2	0.34	0.36		0.16	3	-1.5
1705	22 40	65.0	9.2	B5	—	0.33:	0.28:		0.23	1	-1.9
1717	22 44	64.5	7.0	B3	B3	0.16	0.27		0.26	1	-3.0
1729	22 50	64.8	9.1	A0	A0	0.49	0.48	0.04	0.22	1	-0.3
1758	23 4	65.1	7.0	A2	A2	0.67	0.81	0.20	0.26	2	+1.5
1760	23 5	64.3	8.2	B3	—	0.31	0.34		0.07	1	-1.7
1761	23 5	64.7	8.7	B8	A	0.44	0.54		0.17	2	-0.3
1764	23 5	64.7	6.5	B5	B5	0.35	0.42		0.16	4 (6)	-1.1
1779	23 11	64.9	7.6	F2	F2	0.27	0.34	0.74	0.51	1	+3.3
1780	23 11	64.5	7.9	F2	F5	0.30	0.29	0.70	0.53	1	+3.3
1788	23 16	64.8	8.6	A3	F0	0.63	0.72	0.88	0.36	1	+2.3
1811	23 23	64.8	8.6	B8	A0	0.58	0.74		0.20	1	+0.7
1819	23 28	65.2	6.7	A3	F0	0.61	0.72	0.40	0.42	1	+2.5
1825	23 29	64.7	8.7	A3	A2	0.53	0.68	0.29	0.41	1	+2.5

Cont.

B.D.	α (1900)	δ (1900)	m_{ph}	Sp. U.	Sp. H.	H γ	H δ	K	C	n	M_{ph}
64° 1836	23 ^h 35 ^m	64° .3	8.4	A 2	A 0	0.75	0.82	0.11	0.23	1 (3)	+ 1.3
1861	23 44	64.3	6.6	B 8	A 0	0.58	0.69		0.10	2	+ 0.6
1875	23 49	65.2	8.4	A 0	A 0	0.75	0.85		0.31	1 (4)	+ 1.9
1883	23 54	64.3	8.5	F 0	A 3	0.36	0.44	0.42	0.29	1	+ 2.0
1887	23 57	64.9	8.1	F 5	F 5	0.22	0.27	0.76	0.64	1 (4)	+ 4.0
1900	0 2	64.8	8.8	B 8	A 0	0.59	0.70		0.24	1 (3)	
65° 10	0 6	65.5	8.6	A 0	A 0	0.67	0.68	0.13	0.32	1 (4)	+ 2.0
11	0 6	65.9	8.8	A 0	A 0	0.71	0.92	0.09	0.18	1 (4)	+ 1.0
13	0 7	65.6	7.4	A 0	A 0	0.56	0.73		0.11	2 (6)	+ 0.6
21	0 9	65.8	8.4	A 2	A 3	0.62	0.70	0.29	0.40	2 (5)	+ 2.5
41	0 17	65.9	8.0	A 3	A 5	0.52	0.56	0.34	0.52	2 (6)	+ 2.5
48	0 18	65.7	8.6	F 2	F 0	0.26	0.28	0.64	0.54	1	+ 3.6
54	0 21	66.2	9.1	A 0	A 0	0.70	0.77	0.11	0.16	1	+ 1.0
57	0 22	65.6	8.8	A 5	F 0	0.42	0.49	0.48	0.47	1	
67	0 26	65.9	6.0	B 8	B 5	0.42	0.51		0.11	6 (7)	− 0.4
70	0 29	66.2	6.5	B 8	B 9	0.53	0.70		0.11	4 (6)	+ 0.5
81	0 36	65.3	7.4	F 5	F 8	0.18	0.20	0.81	0.67	2	+ 4.5
88	0 40	65.9	8.1	F 8	G 0	0.18	0.20	0.69	0.71	1	+ 4.5
103	0 46	65.3	8.2	A 0	A 2	0.76	0.87	0.10	0.27	1	+ 1.6
106	0 48	65.9	7.3	F 2	F 0	0.35	0.42	0.60	0.51	2	+ 2.3
110	0 50	65.9	8.2	B 8	A 0	0.38	0.43		0.12	1	− 1.0
115	0 52	65.8	5.9	B 8	B 9	0.64	0.77		0.17	6	+ 0.9
129	0 59	65.4	7.3	B 8	B 8	0.40	0.49		0.10	4	− 0.6
130	0 59	65.9	8.7	B 8	A 0	0.60	0.76		0.22	2	+ 1.2
145	1 10	65.6	8.8	F 0	F 5	0.34	0.35	0.59	0.56	1	+ 2.5
151	1 12	65.6	8.6	B 8	A 0	0.39	0.45		0.31	1	− 0.8
163	1 20	65.3	9.1	A 0	A	0.53	0.59		0.18	1	+ 0.2
175	1 24	65.6	6.1	A 0	A 0	0.75	0.91	0.12	0.22	3	+ 1.2
182	1 29	65.7	8.5	B 8	B 9	0.37	0.49		0.35	2	− 0.8
193	1 34	65.9	8.3	A 5 [A 2]	A 3	0.46	0.42	0.22	0.49	2	
216	1 50	65.9	9.1	F 2	F 5	0.20	0.23	0.63	0.55	1	+ 4.2
239	2 7	66.1	6.6	F 2 [A 2]	$\left\{ \begin{array}{l} F 5 \\ A 2 \end{array} \right.$	0.23	0.32	0.20	0.58	2	+ 3.5
242	2 7	65.9	7.3	F 2	F 5	0.23	0.26	0.60	0.50	2	+ 3.9
248	2 13	65.3	8.0	A 0	A 2	0.67	0.80	0.04	0.22	2	+ 1.2
289	2 37	65.3	var.	B 8	B 8	0.57	0.72		0.23	1 (2)	+ 0.6
300	2 44	65.2	7.3	A 2	A 2	0.59	0.64	0.15	0.18	1 (2)	+ 0.5

Cont.

B.D.	α (1900)	δ (1900)	m_{ph}	Sp. U.	Sp. H.	H γ	H δ	K	C	n	M_{ph}
65° 306	2 ^h 47 ^m	65° 4	7.6	A 0	A 0	0.63	0.74	0.07	0.09	2 (3)	+0.8
322	3 1	66.1	8.4	A 3	A 5	0.53	0.59	0.50	0.46	1 (2)	+2.5
325	3 3	65.5	8.4	A 0	A 0	0.59	0.69	0.15	0.26	1 (2)	
326	3 4	65.5	8.3	A 2	A 2	0.70	0.76	0.15	0.25	2 (3)	+1.4
330	3 6	65.9	9.2	F 0	F 5	0.37	0.37	0.73	0.51	1	+2.4
335	3 8	66.0	6.7	A 0	A 0	0.76	0.90	0.11	0.25	1 (3)	+1.4
338	3 9	65.3	6.6	A 0	A 2	0.71	0.80	0.15	0.20	3	+1.0
340	3 11	65.3	5.0	B 5	B 3 p	0.21	0.28		0.03	2	-2.6
348	3 24	65.2	7.2	A 2	A 2	0.64	0.79	0.14	0.25	2 (3)	+1.4
353	3 30	65.3	7.6	A 0	A 0	0.81	0.84	0.11	0.30	2	+1.8
357	3 33	65.8	7.9	A 2	A 2	0.76	0.80	0.25	0.37	2	+2.4
358	3 34	65.7	8.7	A 2	A 3	0.69	0.78	0.22	0.31	2	+1.9
359	3 34	65.7	8.1	F 5	F 0	0.28	0.28	0.57	0.57	2	+3.5
372	3 43	66.0	(9.8)	A 0	A 0	0.58	0.59	0.05	0.31	1	+1.9
381	3 49	65.3	8.1	A 0	A 0	0.81	0.87	0.07	0.27	1	+1.6
382	3 50	65.6	9.1	A 3	A 2	0.63	0.63	0.42	0.29	1	+1.8
391	3 57	65.2	6.2	A 2	A 2	0.70	0.71	0.22	0.39	3	+2.5
392	3 58	65.6	9.1	A 0	A 0	0.69	0.77	0.08	0.31	1	+1.9
432	4 40	65.5	8.8	F 8	G 0	0.14	0.26	0.67	0.66	1	+4.4
446	4 51	65.2	8.8	A 0	A 0	0.70	0.86	0.04	0.38	1	+2.5
459	5 2	65.9	8.3	A 0	A 0	0.72	0.79	0.08	0.19	2	+1.0
464	5 4	65.9	8.1	F 2	F 2	0.30	0.36	0.63	0.60	2	+2.9
470	5 12	65.8	9.9	B 8	A 2	0.70	0.91		0.21	1	+1.1
480	5 26	65.6	8.9	A 0	A 0	0.61	0.81	0.10	0.27	1 (2)	+1.6
482	5 28	65.1	7.9	A 2	A 2	0.63	0.73	0.26	0.42	2 (3)	+2.5
488	5 36	65.9	8.7	A 5	A 3	0.42	0.57	0.39	0.51	2 (3)	
495	5 39	65.1	8.9	A 0	A 0	0.68	0.80	0.07	0.35	2 (3)	+2.2
497	5 41	65.7	7.1	F 5 [A 3]	F 8	0.21	0.33	0.28	0.81	2 (3)	
507	5 51	65.5	6.8	A 2	A 3	0.52	0.62	0.35	0.38	3	+2.5
510	5 56	65.2	8.5	F 0	F 2	0.38	0.44	0.57	0.45	1	+1.8
511	5 57	65.4	7.9	A 3	A 3	0.65	0.68	0.34	0.43	1 (2)	+2.5
528	6 19	65.5	9.1	A 5	A 2	0.64	0.76	0.37	0.46	1	+2.5
533	6 24	65.4	7.8	F 2	F 2	0.29	0.34	0.57	0.56	2	+3.1
538	6 31	65.1	8.8	F 8	G 0	0.21	0.18	0.84	0.63	1	+4.4
541	6 33	65.1	8.7	F 0	F 2	0.35	0.54	0.60	0.46	1	+2.0
550	6 48	65.4	8.8	F 5	F 5	0.20	0.20		0.53	1	+4.4
553	6 52	65.9	7.8	A 0	A 0	0.79	0.88	0.25	0.11	2	+1.0
576	7 26	65.9	8.7	F 2	G 0	0.20	0.23	0.69	0.55	1	+4.2

Cont.

B.D.	α (1900)	δ (1900)	m_{ph}	Sp. U.	Sp. H.	H γ	H δ	K	C	n	M_{ph}
65° 585	7 ^h 33 ^m	65° .2	8.5	F5	F5	0.16	0.24	0.65	0.54	2	+4.4
586	7 33	65.5	8.4	A5	F0	0.47	0.53	0.25	0.46	2	
591	7 36	64.9	8.1	F5	F5	0.24	0.24	0.58	0.63	2	+4.0
606	7 51	65.0	7.1	A5	F0	0.53	0.57	0.48	0.49	2	+2.5
607	7 54	65.4	7.9	F2	F2	0.37	0.38	0.53	0.56	1	+2.3
623	8 9	65.1	8.7	F5	F5	0.24	0.29	0.81	0.42	1	+3.7
632	8 16	65.0	7.9	F2	F5	0.30	0.32	0.51	0.55	1	+3.2
638	8 26	65.5	5.7	B8	A0	0.56	0.62		0.35	2 (3)	+2.2
953	13 38	65.3	6.0	A0	A0	0.80	0.85	0.12	0.30	3	+1.8
957	13 41	65.5	8.2	F5	F5	0.23	0.27	0.71	0.59	1	+3.9
961	13 42	65.1	8.0	A0	A2	0.74	0.80	0.12	0.26	1	+1.5
987	14 14	65.3	7.4	A5 [A0]	A0	0.51	0.51	0.10	0.57	2	
991	14 17	64.8	8.2	A3	A5	0.46	0.53	0.34	0.43	2	
1011	14 43	65.7	7.6	F5	F5	0.18	0.28	0.64	0.70	1	+4.1
1012	14 44	65.0	8.0	B8	A0	0.44	0.56		0.13	1	−0.2
1015	14 46	65.7	7.9	F0	A5	0.57	0.58	0.52	0.45	1	+2.5
1048	15 17	65.8	7.8	A2	A2	0.66	0.78	0.18	0.28	1	+1.7
1061	15 32	65.5	8.6	A3	A3	0.56	0.66	0.35	0.42	2	+2.5
1062	15 34	65.6	7.5	A2	A2	0.78	0.90	0.20	0.30	3	+1.8
1081	15 49	65.1	7.0	A0	A0	0.75	0.84	0.10	0.18	2	+1.0
1095	15 59	65.2	6.8	A2	A2	0.74	0.84	0.20	0.26	1	+1.5
1097	16 4	65.6	8.8	A5	F0	0.45	0.47	0.45	0.37	1	
1115	16 20	65.2	8.8	A5	A5	0.51	0.57	0.27	0.44	1	
1157	16 55	65.3	5.4	F5	F5	0.18	0.22	0.70	0.64	5	+4.4
1159	16 56	65.2	6.6	F2	F0	0.38	0.41	0.61	0.53	3 (2)	+2.0
1170	17 8	65.8	3.0	B8	B5	0.38	0.42		0.11	4	−1.0
1176	17 20	65.7	8.0	F2	F2	0.32	0.35	0.64	0.52	1	+2.8
1220	17 54	65.0	8.6	F2	F8	0.20	0.26	0.59	0.60	1 (2)	+4.1
1233	18 1	65.9	8.0	F5	F5	0.28	0.26	0.68	0.61	1 (2)	+3.6
1245	18 7	65.9	8.0	A0	A2	0.79	0.90	0.06	0.13	1 (2)	+1.0
1262	18 20	65.3	8.4	F2	F8	0.29	0.26	0.59	0.56	1 (2)	+3.5
1276	18 31	65.4	7.0	F0 [A2]	A3	0.60	0.55	0.21	0.60	1	+2.5
1283	18 36	65.4	6.2	F0 [A5]	A3	0.46	0.58	0.33	0.50	1	
1326	19 9	65.8	6.2	A0	A2	0.78	0.87	0.08	0.13	3	+1.0
1333	19 14	65.1	7.3	A0	A0	0.73	0.81	0.11	0.17	1	+1.0
1335	19 15	65.9	8.0	F8	F5	0.24	0.34	0.69	0.55	1	+3.4
1345	19 20	65.5	4.7	A0	A2	0.82	0.89	0.12	0.20	2	+1.0
1365	19 31	65.7	8.7	A2	A0	0.61	0.74	0.35	0.36	2	+2.3

Cont.

B.D.	α (1900)	δ (1900)	m_{ph}	Sp. U.	Sp. H.	H γ	H δ	K	C	n	M_{ph}
65° 1369	19 ^h 33 ^m	65° .3	8.0	A 2	A 3	0.64	0.69	0.17	0.41	2	+2.5
1381	19 38	65.2	8.7	F 0	F 0	0.44	0.45	0.51	0.56	1	
1406	19 48	65.7	8.8	F 8	F 8	0.10	0.24	0.86	0.59	1	+4.7
1423	20 1	65.6	8.7	F 5	F 5	0.26	0.25	0.74	0.60	1	+3.8
1433	20 6	66.0	7.0	A 0	A 0	0.79	0.88	0.11	0.28	1 (2)	+1.3
1443	20 15	65.5	8.2	F 8	F 5	0.17	0.19	0.58	0.65	1	+4.6
1466	20 27	65.4	6.6	A 2	A 2	0.71	0.76	0.22	0.33	3 (6)	+2.1
1468	20 27	65.5	8.9	F 2	F 0	0.36	0.38	0.60	0.51	2	+2.4
1482	20 34	65.2	8.8	A 0	B 9	0.64	0.71	0.03	0.27	1	+1.6
1485	20 36	66.0	9.0	F 8	F 2	0.19	0.19	0.54	0.58	1	+4.5
1488	20 38	66.1	9.2	A 3	A 5	0.59	—		0.30	1	+1.8
1499	20 42	65.9	6.9	B 8	B 9	0.61	0.74		0.17	1 (3)	+0.8
1518	20 54	65.3	7.1	B 8	B 9	0.58	0.68		0.14	2	+0.5
1552	21 8	65.3	7.7	B 8	B 9	0.67	0.77		0.12	2 (3)	+0.9
1565	21 14	65.4	8.4	A 5	F 0	0.53	0.55	0.44	0.48	1 (2)	
1581	21 21	65.7	8.7	A 0	A 0	0.79	0.80	0.09	0.25	1 (2)	+1.4
1602	21 32	65.3	7.7	A 0	A 0	0.76	0.84	0.11	0.26	3	+1.5
1634	21 40	65.9	8.0	A 2	A 0	0.68	0.76	0.23	0.32	3	+2.0
1647	21 44	65.5	8.4	A 3	A 2	0.64	0.72	0.35	0.36	2	+2.3
1654	21 46	66.8	8.9	A 2	—	0.70	0.82	0.11	0.30	1	+1.8
1662	21 48	65.4	8.9	A 0	A 2	0.59	0.71	0.08	0.20	1	+0.7
1664	21 49	65.3	6.5	F 0 [A 2]	A 2 G	0.48	0.54	0.10	0.49	1	
1680	21 53	65.2	7.1	A 0	A 0	0.56	0.69	0.09	0.17	1	+0.5
1682	21 53	65.9	9.5	A 2	—	0.67	0.72	0.34	0.42	1	+2.5
1683	21 53	65.9	8.6	A 0	A 0	0.68	0.75	0.10	0.16	1	+0.9
1690	21 54	65.5	7.8	F 8	G 5	0.12	0.19	0.88	0.71	1	+4.8
1691	21 55	65.7	6.4	B 0	B 3	0.24	0.35		0.19	1	—2.0
1704	21 58	65.6	8.3	B 5	B 8	0.27	0.39		0.17	2	—1.7
1708	21 59	65.4	8.1	A 0	A 0	0.73	0.79	0.11	0.27	1	+1.6
1712	22 0	65.6	6.9	A 0	B 8	0.49	0.66	0.04	0.24	1	
1720	22 3	65.8	9.1	A 0	A 2	0.57	0.81	0.03	0.18	1	+0.8
1722	22 3	66.2	8.6	F 5	F 5	0.24	0.34	0.73	0.64	1	+3.4
1726	22 7	65.8	8.7	A 2	A 2	0.59	0.73	0.34	0.37	1	+2.4
1728	22 8	65.8	8.0	A 0	A 0	0.61	0.71	0.07	0.31	2	+1.9
1745	22 14	65.4	8.9	F 0	—	0.45	0.41	0.45	0.60	1	
1746	22 14	65.6	7.0	A 0	A 0	0.62	0.71	0.05	0.18	2 (4)	+0.7
1754	22 17	65.9	8.4	A 0	A 0	0.75	0.86	0.06	0.18	3	+1.0

Cont.

B.D.	α (1900)	δ (1900)	m_{ph}	Sp. U.	Sp. H.	H γ	H δ	K	C	n	M_{ph}
65° 1759	22 ^k 19 ^m	66° .2	6.9	F2 [A 2]	$\begin{cases} F5 \\ A2 \end{cases}$	0.34	0.40	0.26	0.64	1	+2.4
1774	22 27	65.9	8.5	B3	B8	0.20	0.23		0.34	2	-3.0
1786	22 33	65.6	8.9	A0	A2	0.67	0.79	0.07	0.31	1	+1.9
1789	22 35	65.6	7.4	A0	A0	0.74	0.91	0.13	0.26	1 (3)	+1.5
1811	22 46	65.5	8.7	A0	A0	0.67	0.77	0.16	0.28	1	+1.7
1813	22 46	66.0	6.7	B8	B9	0.42	0.51		0.15	1 (2)	-0.4
1821	22 48	65.5	9.3	A2	A2	0.66	0.79	0.26	0.23	1	+1.3
1826	22 49	66.1	8.0	A2	A2	0.66	0.76	0.14	0.22	2 (3)	+1.2
1827	22 49	65.9	9.1	A0	—	0.77	0.76	0.12	0.25	1	+1.4
1837	22 54	65.9	9.2	F2	—	0.30	0.34	0.59	0.56	1	+3.0
1850	23 5	65.5	8.0	A0	A3	0.75	0.82	0.08	0.21	2	+1.1
1877	23 16	65.9	8.4	B8	B9	0.53	0.52		0.16	1	0.0
1883	23 20	66.2	9.1	B8	A	0.52	0.58		0.25	1	
1887	23 21	65.7	8.7	A3	F0	0.51	0.66	0.43	0.38	1	+2.5
1935	23 39	65.9	8.0	B8	B9	0.39	0.45		0.18	2 (6)	-0.8
1943	23 42	66.2	5.7	B3	B3	0.23	0.30		0.11	6 (7)	-2.4
1946	23 43	65.7	8.7	A2	A0	0.61	0.74	0.23	0.37	1 (4)	+2.4
1948	23 43	66.1	8.3	A2	A0	0.71	0.84	0.26	0.27	2 (5)	+1.6
1985	23 57	65.9	7.1	B8	B9	0.72	0.87		0.11	2 (6)	+1.0
1994	23 59	65.3	8.5	A0	A0	0.70	0.87	0.15	0.32	1 (4)	+2.0
2001	0 2	65.9	8.8	A2	F0	0.64	0.72	0.29	0.38	1 (4)	+2.5
66° 1	0 3	66.7	8.7	A5	F0	0.53	0.57	0.44	0.47	1 (4)	
15	0 14	66.8	8.0	B8	A0	0.68	0.75		0.16	2 (5)	+0.9
20	0 16	66.5	7.0	A0	A0	0.69	0.87	0.07	0.14	3 (7)	+1.0
35	0 26	66.6	8.4	B5	B8	0.18	0.34		0.30	2	-2.5
39	0 29	66.9	7.5	A2	A3	0.60	0.75	0.26	0.27	3	+1.6
53	0 36	67.2	8.6	A2	F0	0.57	0.76	0.38	0.46	1	+2.5
55	0 38	66.5	8.5	F0 [A 5]	F8	0.54	0.45	0.31	0.50	1	
58	0 39	66.6	7.3	F8	F8	0.21	0.30	0.78	0.58	1	+3.8
79	0 52	66.9	8.5	F2	F2	0.34	0.41	0.59	0.54	2	+2.4
103	1 13	66.7	9.2	A0	A0	0.72	0.83	0.19	0.36	1	+2.3
105	1 14	66.7	8.7	F0 [A 3]	A3	0.45	0.54	0.28	0.49	1	
114	1 20	66.5	8.8	F0	F0	0.39	0.46	0.58	0.48	1	+1.7
115	1 20	67.2	9.1	F0	F5	0.25	0.32	0.62	0.48	1	+3.4
116	1 20	66.5	9.5	B3	A	0.25	0.32		0.34	1	-2.2
119	1 21	66.7	9.2	B8	A3	0.38	0.46		0.32	1	-0.9

Cont.

B.D.	$\alpha(1900)$	$\delta(1900)$	m_{ph}	Sp. U.	Sp. H.	H γ	H δ	K	C	n	M_{ph}
66° 126	1 ^h 26 ^m	66° 7	8.7	A 2	A 3	0.64	0.79	0.37	0.36	1	+2.3
134	1 29	67.1	7.2	A 0	A 0	0.69	0.81	0.11	0.19	3 (4)	+1.0
151	1 36	66.5	9.0	B 8	A 2	0.49	0.55		0.30	1	-0.1
156	1 41	66.7	8.8	F 0	F 0	0.47	0.47	0.49	0.46	2	
161	1 42	67.2	8.5	F 5	F 5	0.17	0.19	0.73	0.61	2	+4.6
171	1 51	67.1	7.8	A 0	A 0	0.76	0.88	0.12	0.19	1	+1.0
173	1 51	66.7	8.6	A 0	A 2	0.75	0.75	0.11	0.28	1	+1.7
175	1 52	66.6	7.5	A 2	A 3	0.70	0.83	0.29	0.32	1	+2.0
183	1 59	67.2	9.1	F 0	A 5	0.38	0.42	0.46	0.54	1	+2.0
185	1 59	66.5	9.4	B 8	A 2	0.39	0.40		0.24	1	-1.1
208	2 17	66.4	8.8	A 0	A 0	0.62	0.75	0.12	0.25	1	+1.4
213	2 21	66.9	4.7	A 3	A 5 p	0.68	0.77	0.30	0.37	4	+2.4
214	2 21	66.9	8.4	B 8	A 0	0.56	0.65		0.18	2	+0.4
219	2 26	66.9	8.0	A 0	A 0	0.73	0.85	0.05	0.21	2 (3)	+1.1
223	2 28	67.1	7.6	F 2	F 2	0.26	0.32	0.62	0.46	2 (3)	+3.4
251	3 8	66.7	8.1	A 5 [A 0]	A 2	0.57	0.54	0.14	0.51	1 (2)	+2.5
266	3 16	66.8	9.2	F 2	—	0.26	0.26	0.88	0.56	1	+3.8
267	3 16	66.9	9.1	B 8	—	0.41	0.47	0.02	0.24	1	-0.7
275	3 26	66.9	9.1	B 8	A 0	0.54	0.64		0.26	1	
284	3 37	66.9	6.1	F 2	F 2	0.41	0.45	0.61	0.50	6	+1.5
301	3 52	66.8	8.7	A 0	A 2	0.64	0.72	0.15	0.21	1	+1.1
315	4 8	66.7	8.8	F 2	—	0.33	0.34	0.54	0.50	2	+2.8
316	4 8	66.8	6.9	B 8	B 8	0.70	0.76		0.11	2 (6)	+1.0
318	4 13	67.0	8.8	F 2	F 0	0.34	0.35	0.63	0.55	2	+2.7
325	4 16	66.7	8.4	B 8	B 9	0.49	0.59		0.17	2	0.0
331	4 21	66.4	8.9	A 0	A 0	0.69	0.71	0.07	0.38	2	+2.5
335	4 29	66.9	7.8	B 8	A 0	0.49	0.60		0.14	1	+0.1
336	4 30	66.7	9.1	A 2	A 0	0.65	0.80	0.17	0.32	1	+2.0
340	4 32	67.1	7.9	B 8	A 0	0.76	0.79		0.22	1	+1.2
351	4 39	66.8	8.9	B 8	A 0	0.70	0.79		0.14	1	+1.0
358	4 44	66.2	4.6	B 0	B 0	0.11	0.21		0.30	1	-3.6
362	4 45	66.8	8.0	B 8	B 9	0.69	0.77		0.23	2	+1.3
370	4 53	66.7	6.8	F 5	F 8	0.18	0.21	0.79	0.69	2 (4)	+4.5
380	5 6	66.1	8.9	A 0	A 0	0.65	0.82	0.09	0.26	1	+1.5
387	5 12	66.9	8.3	F 2	K 0	0.35	0.39	0.68	0.58	1	+2.4
391	5 13	66.1	8.3	A 2	A 0	0.73	0.85	0.18	0.36	1 (2)	+2.3
394	5 18	66.6	9.2	A 2	A 5	0.52	0.57	0.13	0.45	1	+2.5
400	5 23	66.4	9.4	A 3	A 0	0.56	0.74	0.28	0.53	1	+2.5

Cont.

B.D.	α (1900)	δ (1900)	m_{ph}	Sp. U.	Sp. H.	H γ	H δ	K	C	n	M_{ph}
66° 401	5 ^h 27 ^m	66° .6	6.4	A 3	A 5	0.56	0.61	0.30	0.39	6	+2.5
405	5 33	66.5	8.6	A 2	A 2	0.71	0.82	0.20	0.34	2	+2.2
419	5 50	67.0	7.0	A 3	A 0	0.69	0.76	0.47	0.38	1 (3)	+2.5
423	5 55	66.9	8.0	F 2	F 5	0.36	0.39	0.64	0.54	1 (2)	+2.3
425	5 56	66.3	8.0	A 2	A 2	0.69	0.90	0.24	0.33	1 (2)	+2.1
435	6 5	66.2	7.3	F 5	F 5	0.18	0.27	0.61	0.59	2 (3)	+4.1
441	6 14	66.6	8.5	F 2	F 0	0.32	0.36	0.52	0.48	2	+2.8
451	6 26	66.1	8.9	A 5	F 0	0.45	0.58	0.46	0.45	1	
455	6 29	66.2	7.6	B 8	B 8	0.41	0.56		0.15	2	-0.4
460	6 32	66.3	7.5	F 8	F 8	0.14	0.33	0.93	0.74	1	
463	6 34	66.4	8.0	F 8	F 8	0.16	0.23	0.75	0.63	1	+4.4
467	6 40	66.4	8.6	F 5	G 0	0.17	0.26	0.79	0.61	1	+4.2
480	6 59	66.2	8.1	A 3	A 2	0.73	0.79	0.31	0.36	2	+2.3
498	7 15	66.0	7.7	A 3	A 5	0.56	0.59	0.26	0.49	2	+2.5
502	7 18	66.5	6.4	B 8	B 9	0.53	0.61		0.06	3	+0.2
503	7 18	66.7	7.6	F 0 [A 2]	A 5	0.62	0.59	0.17	0.53	1	+2.5
517	7 30	66.5	8.4	A 0	A 0	0.66	0.75	0.11	0.11	2	+0.9
519	7 32	66.5	8.4	A 2	A 2	0.78	0.81	0.19	0.26	2	+1.5
528	7 45	66.7	8.6	F 5	F 2	0.25	0.31	0.64	0.45	2	+3.5
533	7 55	66.8	8.5	A 2	A 2	0.69	0.80	0.24	0.31	1	+1.9
538	8 2	66.3	8.6	F 2	F 0	0.30	0.34	0.51	0.40	1	+3.1
541	8 6	66.5	7.1	F 0	F 2	0.36	0.42	0.58	0.38	1	+2.1
545	8 14	66.3	8.5	F 8	F 8	0.21	0.21	0.66	0.67	1	
548	8 15	66.6	8.6	A 0	A 2	0.68	0.78	0.15	0.15	1	+1.0
816	13 39	65.3	6.8	A 0	A 2	0.65	0.72	0.18	0.29	1	+1.8
821	13 48	66.5	8.2	F 0	F 0	0.43	0.42	0.60	0.52	1	+1.6
824	13 53	66.6	8.7	B 5	G p	0.09	0.19		0.06	1	-3.8
827	13 56	66.6	7.9	F 5	F 5	0.25	0.21	0.82	0.58	1	+4.1
828	13 58	66.6	8.7	F 0	F 5	0.34	0.41	0.57	0.55	1	+2.3
842	14 19	65.8	7.7	F 5	F 5	0.28	0.27	0.63	0.63	2	+3.5
847	14 23	66.4	7.7	F 5	F 2	0.23	0.24	0.66	0.57	2	+4.0
855	14 32	65.8	7.2	F 8	F 5	0.16	0.20	0.76	0.67	1	+4.6
856	14 33	66.4	8.2	F 2	F 0	0.34	0.36	0.54	0.50	1	+2.7
870	14 46	65.9	8.8	F 2	F 8	0.29	0.26	0.56	0.67	1	+3.6
872	14 48	65.9	8.7	F 5	G 0	0.18	0.24	0.73	0.72	1	+4.3
886	15 1	66.2	7.9	F 8	G 0	0.16	0.20	0.80	0.76	1	+4.6
887	15 2	66.3	6.4	A 2	A 0	0.75	0.90	0.12	0.23	6	+1.3
889	15 5	66.1	8.3	A 0	A 0	0.73	0.82	0.09	0.29	2	+1.8

Cont.

B.D.	α (1900)	δ (1900)	m_{ph}	Sp. U.	Sp. H.	H γ	H δ	K	C	n	M_{ph}
66° 894	15 ^h 10 ^m	66° 4	7.9	A 5	A 2	0.52	0.54	0.45	0.33	2	
895	15 11	66.6	9.1	A 0	A 0	0.63	0.78	0.11	0.26	1	+ 1.5
904	15 18	66.4	8.8	F 2	F 8	0.29	0.34	0.69	0.57	1	+ 3.1
918	15 45	65.9	8.7	F 5	F 8	0.24	0.25	0.73	0.68	2	+ 4.0
920	15 46	66.2	8.3	A 2	A 3	0.59	0.62	0.28	0.39	2	+ 2.5
923	15 50	66.7	8.4	A 3	A 3	0.63	0.72	0.34	0.46	1	+ 2.5
927	15 58	66.3	8.5	F 0	A 3	0.54	0.62	0.45	0.43	1	+ 2.5
930	16 2	65.9	8.9	A 3	A 2	0.57	0.63	0.42	0.45	1	+ 2.5
975	16 46	66.2	7.8	A 2	A 2	0.72	0.71	0.29	0.34	1	+ 2.2
999	17 11	66.4	7.6	A 3	A 2	0.58	0.68	0.35	0.24	1	
1077	18 5	66.9	7.4	F 5	F 5	0.24	0.31	0.54	0.72	1 (2)	+ 3.5
1089	18 14	66.4	8.4	F 0	F 0	0.40	0.44	0.43	0.43	1 (2)	+ 1.7
1112	18 34	66.3	7.6	A 0	A 0	0.78	0.89	0.13	0.17	1	+ 1.0
1142	18 54	66.9	7.5	A 0	A 0	0.79	0.89	0.12	0.18	2	+ 1.0
1154	19 4	66.3	8.1	A 3	A 3	0.63	0.65	0.36	0.39	1	+ 2.5
1179	19 14	66.9	6.8	A 0	A 2	0.76	0.80	0.11	0.30	1 (2)	+ 1.8
1182	19 16	66.2	9.1	A 0	A 3	0.64	0.75	0.11	0.41	1	+ 2.5
1184	19 16	66.9	7.7	B 3	B 5	0.15	0.20		0.07	1	- 3.4
1225	19 39	66.2	8.1	A 2	A 2	0.61	0.65	0.27	0.35	2	+ 2.2
1253	19 52	66.4	7.8	A 3	F 0	0.65	0.73	0.40	0.40	1	+ 2.5
1254	19 52	66.8	8.7	F 2	F 5	0.28	0.24	0.78	0.56	1	+ 3.8
1269	20 5	66.2	9.2	A 2	A 2	0.56	0.57	0.26	0.38	1	+ 2.5
1311	20 36	67.2	7.7	B 8	B 9	0.47	0.59		0.10	2 (3)	- 0.1
1313	20 39	66.9	8.6	F 5	F 8	0.19	0.24	0.70	0.53	1 (2)	+ 4.3
1316	20 41	66.6	8.8	F 0	A 5	0.47	0.55	0.43	0.45	1 (2)	
1318	20 42	66.3	5.9	A 3	A 5	0.58	0.65	0.35	0.39	2	+ 2.5
1326	20 45	66.9	8.3	A 0	B 9	0.65	0.76	0.08	0.29	1 (2)	+ 1.8
1344	20 56	66.5	9.1	A 2	A	0.70	0.75		0.26	1 (2)	+ 1.5
1350	21 0	66.3	8.3	A 3	A 2	0.46	0.49	0.34	0.43	2 (3)	
1360	21 6	66.9	8.8	A 3	F 2	0.48	0.57	0.33	0.38	1 (2)	
1375	21 13	66.2	8.6	A 0	A 0	0.82	0.89	0.05	0.17	1 (2)	+ 1.0
1392	21 19	66.3	7.5	B 8	A 0	0.76	0.86		0.18	1 (2)	+ 1.0
1405	21 26	66.4	5.3	B 8	B 5	0.41	0.50		0.02	3	- 0.5
1407	21 27	66.6	6.8	A 0	A 2	0.66	0.72	0.11	0.15	1 (2)	+ 0.9
1441	21 47	66.3	6.9	F 2	F 2	0.34	0.35	0.67	0.50	4	+ 2.7
1446	21 49	66.4	8.6	F 5	F 5	0.24	0.25	0.66	0.57	1	+ 3.9
1455	21 53	66.2	8.1	A 5	F 0	0.45	0.53	0.43	0.42	2	
1470	22 0	66.8	8.7	A 2	A 2	0.58	0.66	0.32	0.33	1	+ 2.1

Cont.

B.D.	α (1900)	δ (1900)	m_{ph}	Sp. U.	Sp. H.	H γ	H δ	K	C	n	M_{ph}
66° 1471	22 ^h 1 ^m	66° .6	8.8	B 5	B 8	0.29	0.40		0.21	1	−1.5
1473	22 3	66.3	8.6	A 2	A 2	0.72	0.84	0.23	0.19	1	+1.0
1474	22 3	67.0	9.2	F 5	F 8	0.26	0.25	0.68 :	0.53	1	+3.9
1484	22 10	66.4	8.9	B 3	B 9	0.28	0.35		0.16	2	−1.8
1488	22 11	66.7	8.8	B 5	—	0.34	0.37		0.23	1	−1.4
1490	22 11	66.4	8.5	A 0	A 0	0.78	0.83	0.08	0.27	2	+1.6
1501	22 18	66.5	7.3	A 5	A 5	0.52	0.56	0.42	0.39	3	
1521	22 29	66.6	9.2	B 0	—	0.09	0.16		0.43	1	−4.0
1527	22 32	67.2	8.4	A 0	A 0	0.75	0.87	0.18	0.22	1	+1.2
1535	22 37	66.6	9.1	A 0 <i>p</i>	A	0.22	0.36	0.13	0.50	1	−2.2
1545	22 44	66.3	9.2	A 3	—	0.57	0.67	0.33	0.41	1	+2.5
1546	22 44	66.4	8.3	F 2	F 0	0.26	0.32	0.76	0.55	1	+3.4
1552	22 47	66.6	8.6	A 2	A 0	0.69	0.81	0.28	0.33	1	+2.1
1558	22 51	66.3	8.9	A 0	—	0.69	0.82		—	1	
1563	22 53	66.3	8.7	B 8	—	0.46	0.54		0.23	2	−0.2
1565	22 53	66.8	8.6	F 8	F 5	0.15	0.18	0.84	0.68	1	+4.7
1569	22 55	66.6	8.8	F 5	G 0	0.21	0.25	0.78	0.56	1	+4.1
1586	23 5	66.6	9.1	A 0	—	0.68	0.77	0.09	0.43	2	+2.5
1587	23 6	66.7	6.5	A 0	A 0	0.72	0.82	0.12	0.13	4 (6)	+1.0
1603	23 18	66.5	9.1	F 0	F	0.44	0.68 :	0.41	0.40	1	+1.0
1607	23 21	66.4	7.5	A 0	A 0	0.66	0.88	0.10	0.15	2	+1.0
1610	23 25	66.5	9.1	A 3	—	0.54	0.69	0.34	0.42	1	+2.5
1615	23 29	67.1	8.6	A 3	A 3	0.58	0.62	0.43	0.51	2 (5)	+2.5
1621	23 31	66.5	8.6	A 5	A 2	0.51	0.56	0.51	0.54	2 (5)	
1630	23 36	66.9	8.6	F 2	F 5	0.36	0.42	0.47 :	0.48	2 (5)	+2.1
1647	23 46	66.4	7.7	F 2	F 2	0.34	0.35	0.62	0.51	2 (5)	+2.6
1654	23 49	66.3	8.6	A 2	A 5	0.59	0.68	0.35	0.36	1 (4)	+2.3
1661	23 53	66.9	9.2	B 5	—	0.14	0.22		0.44	1	−3.3
1662	23 53	66.7	8.5	A 0	A 0	0.72	0.87	0.09	0.23	1 (4)	+1.3
1667	23 54	66.3	8.4	F 2	F 5	0.34	0.40	0.56	0.52	1 (4)	+2.4
67° 5	0 7	67.9	9.1	A 2	A 2	0.67	0.80	0.23	0.38	2 (5)	+2.5
6	0 8	67.6	8.9	F 0 [A 2]	F 5	0.31	0.49	0.21	0.66	2 (4)	+2.0
7	0 8	67.5	8.5	F 0	F 0	0.36	0.38	0.55	0.52	2 (5)	+2.4
15	0 12	68.1	9.1	A 0	A 0	0.66	0.87	0.06	0.21	2 (4)	+1.1
50	0 26	67.4	8.2	A 3	F 0	0.60	0.60	0.44	0.45	2 (5)	+2.5
57	0 31	68.2	8.4	A 5	F 0	0.57	0.61	0.49	0.39	1	+2.5
71	0 43	67.9	8.2	A 0	B 8	0.49	0.65	0.08	0.23	1	+0.2

Cont.

B.D.	α (1900)	δ (1900)	m_{ph}	Sp. U.	Sp. H.	H γ	H δ	K	C	n	M_{ph}
67° 81	0 ^h 50 ^m	68° 2	6.7	F2	F0	0.88	0.40	0.58	0.50	2 (4)	+2.1
98	1 4	67.2	7.1	F8	G0	0.15	0.19	0.76	0.68	3	+4.7
108	1 11	67.3	6.7	A0	A0	0.72	0.84	0.06	0.16	3	+1.0
116	1 16	68.0	8.2	F0	F0	0.41	0.50	0.64	0.51	1	+1.2
134	1 25	67.4	8.0	B8	B9	0.48	0.56		0.11	2	-0.1
137	1 27	67.9	8.4	F0	F0	0.83	0.82	0.74	0.51	1	+2.9
149	1 35	67.5	5.5	B8	A0 p	0.58	0.64		0.10	5	+0.3
155	1 40	68.1	8.8	A0	A0	0.79	0.88	0.16	0.21	2	+1.1
157	1 40	67.2	8.5	F5	F5	0.19	0.15	0.67	0.74	1	+4.7
164	1 44	67.9	7.8	A3	A5	0.63	0.70	0.40	0.37	2	+2.4
165	1 45	67.7	8.3	B8	A0	0.56	0.74		0.08	2	+0.6
168	1 47	67.7	7.2	B8	A0	0.46	0.59		0.10	4	-0.1
169	1 48	68.2	4.4	B8	B8	0.39	0.51		0.10	3	-0.6
181	1 57	68.1	8.1	A0	A2	0.73	0.83	0.10	0.26	1	+1.5
185	2 1	67.8	8.8	A0	A0	0.59	0.72	0.05	0.25	1	+1.4
189	2 6	67.7	8.1	A5	F0	0.53	0.62	0.39	0.40	2	
192	2 9	67.4	9.2	F0	F0	0.41	0.40	0.55	0.55	1	+1.8
215	2 27	67.9	6.8	F2	F2	0.37	0.38	0.76	0.53	3 (4)	+2.3
217	2 30	67.6	7.8	F2	F0	0.35	0.34	0.49	0.46	1 (2)	+2.7
221	2 33	68.0	8.5	B5	B8	0.25	0.31		0.45	1 (2)	-2.2
224	2 36	67.4	6.0	A2	A2	0.64	0.75	0.18	0.27	2	+1.6
257	3 12	67.4	8.1	F5	F5	0.24	0.31	0.67	0.58	1 (2)	+3.6
260	3 12	67.2	8.9	A2	A0	0.68	0.78	0.20	0.29	1 (2)	+1.8
270	3 21	68.1	7.8	B8	B8	0.53	0.61		0.09	1 (2)	+0.2
273	3 23	67.2	8.0	F2	F0	0.32	0.35	0.41	0.50	1 (2)	+2.9
277	3 27	67.6	8.5	F8	F8	0.15	0.24	0.84	0.56	1	+4.4
296	3 43	67.3	7.6	F0	F0	0.43	0.46	0.56	0.47	2	+1.4
299	3 49	68.1	8.3	A5	F0	0.54	0.48	0.40	0.42	1	
310	3 59	68.1	7.5	F0	F0	0.41	0.46	0.32	0.40	1	+1.4
312	4 3	68.1	8.9	A3	A2	0.53	0.62	0.34	0.29	2	+1.8
315	4 7	67.2	9.2	A3	A2	0.58	0.59	0.32	0.37	2	+2.4
319	4 10	67.6	8.7	F8	F8	0.20	0.22	0.81	0.60	2	
325	4 14	67.7	8.2	F5	F2	0.34	0.36	0.68	0.54	2	+2.7
327	4 16	67.8	8.2	B8	B9	0.66	0.74		0.20	2	+1.0
329	4 18	67.5	8.3	F2	F2	0.41	0.41	0.56	0.49	2	+1.8
334	4 23	67.4	7.0	A2	A2	0.64	0.71	0.25	0.34	2 (4)	+2.2
339	4 27	68.1	7.2	B8	B8	0.60	0.72		0.11	3	+0.7
343	4 33	67.9	7.8	B8	A0	0.68	0.79		0.25	1	+1.4

Cont.

B.D.	α (1900)	δ (1900)	m_{ph}	Sp. U.	Sp. H.	H γ	H δ	K	C	n	M_{ph}
67° 347	4 ^h 38 ^m	67° .6	7.2	F0	F0	0.40	0.50	0.42	0.46	1	
351	4 43	68.0	9.1	A0	A0	0.58	0.79	0.09	0.10	2	+0.8
354	4 44	67.8	7.9	F2	F2	0.33	0.38	0.53	0.50	1	+2.5
357	4 47	67.6	7.2	B8	B8	0.47	0.65		0.12	2	+0.2
360	4 48	67.3	8.4	F5	F8	0.24	0.29	0.68	0.62	2	+3.6
364	4 59	67.7	9.1	A2	A2	0.69	0.81	0.19	0.28	2	+1.7
365	5 1	67.5	(9.1)	B8	—	0.39	0.53		0.16	1	—0.5
367	5 2	67.6	7.6	F2	F2	0.34	0.38	0.69	0.63	2	+2.5
371	5 4	67.4	7.1	A0	A0	0.68	0.80	0.09	0.34	1 (2)	+2.2
373	5 4	67.2	7.8	A5	F0	0.63	0.68	0.48	0.43	2 (4)	+2.5
379	5 9	67.9	7.5	A3	A2	0.56	0.69	0.37	0.45	2	+2.5
384	5 18	67.6	8.4	A5	A2	0.55	0.64	0.41	0.42	1 (2)	+2.5
385	5 18	67.8	8.2	B8	B8	0.36	0.41		0.21	1 (2)	—1.2
386	5 20	67.1	8.6	A3	A3	0.53	0.61	0.51	0.52	1 (2)	+2.5
390	5 22	67.9	6.9	F0	F0	0.34	0.38	0.46	0.45	1 (4)	+2.5
396	5 34	67.9	8.0	F0	F0	0.40	0.44	0.57	0.49	2 (3)	
397	5 34	67.2	8.2	A5	F0	0.56	0.63	0.43	0.47	2 (3)	+2.5
405	5 45	67.5	8.2	A5	A3	0.48	0.53	0.35	0.44	2 (3)	
407	5 52	67.3	8.2	A0	A0	0.74	0.84	0.09	0.28	1 (2)	+1.7
413	6 0	67.3	9.2	A2	A0	0.69	0.80	0.17	0.27	1	+1.6
440	6 28	67.2	8.7	A2	A2	0.54	0.63	0.27	0.35	1	+2.2
441	6 30	67.4	7.7	B8	B9	0.66	0.79		0.20	2	+1.0
442	6 31	67.2	8.9	A0	A0	0.79	0.79	0.06	0.26	1	+1.5
447	6 37	66.9	8.6	F8	F8	0.15	0.17	0.32	0.66	1	+4.8
454	6 41	67.7	5.0	B3	B3	0.31	0.54		0.04	2	—0.9
458	6 43	67.3	8.2	A2	A2	0.59	0.74	0.22	0.27	1	+1.6
461	6 45	67.4	8.7	A2	A2	0.59	0.71	0.28	0.31	2	+1.9
486	7 15	67.3	7.6	B8	A0	0.60	0.79		0.22	1	+1.2
489	7 19	67.6	8.9	F2	F5	0.28	0.36	0.45	0.46	1	+3.0
499	7 29	67.3	8.2	F0	F0	0.42	0.45	0.46	0.42	2	+1.5
504	7 33	67.8	9.1	A0	A0	0.67	0.82	0.08	0.14	2	+1.0
506	7 36	67.1	8.4	A3	A5	0.54	0.60	0.33	0.35	2	+2.2
525	8 1	67.5	8.6	F8	G0	0.17	0.18	0.73	0.55	1	+4.6
792	15 35	67.1	7.8	A0	A2	0.76	0.85	0.13	0.25	1	+1.4
831	14 17	67.6	8.4	A5	A3	0.48	0.60	0.35	0.43	2	
843	14 33	67.2	8.0	F5	F8	0.21	0.25	0.50	0.77	1	
873	15 11	67.3	8.7	F5	F8	0.26	0.26	0.79	0.59	1	+3.8
876	15 13	67.7	5.9	F8	G0	0.19	0.22	0.79	0.76	2	+4.4

Cont.

B.D.	$\alpha(1900)$	$\delta(1900)$	m_{ph}	Sp. U.	Sp. H.	H γ	H δ	K	C	n	M_{ph}
67° 883	15 ^h 19 ^m	67° 4	8.2	A 5	A 5	0.43	0.51	0.44	0.45	1	
901	15 30	67.0	8.5	F 2	F 0	0.39	0.39	0.50	0.51	2	+ 2.1
903	15 32	67.4	8.9	F 0	F 0	0.43	0.48	0.48	0.50	1	
912	15 40	67.7	8.6	A 2	A 2	0.56	0.56	0.14	0.37	2	+ 2.4
916	15 43	67.6	8.8	F 2	F 2	0.35	0.42	0.56	0.50	2	+ 2.2
917	15 44	67.1	8.3	A 2	A 2	0.60	0.65	0.30	0.32	2	+ 2.0
926	16 5	67.3	8.8	A 3	A 0	0.74	0.73	0.28	0.36	1	+ 2.3
945	16 30	67.6	8.9	F 5	G 0	0.26	0.28	0.65	0.62	1	+ 3.6
961	16 40	67.8	9.1	A 0	—	0.79	0.76	0.17	0.35	1	+ 2.2
974	16 52	67.8	8.4	F 8	G 5	0.17	0.22	0.67	0.56	1	+ 4.4
977	16 56	67.6	6.6	A 0	A 0	0.68	0.80	0.06	0.12	2	+ 1.0
995	17 13	67.7	8.4	A 5	A 3	0.54	0.62	0.36	0.35	1	+ 2.5
1015	17 27	67.8	7.6	A 5	A 5	0.57	0.60	0.42	0.37	2	+ 2.4
1017	17 30	67.0	8.3	A 3	—	0.67	0.71	0.28	0.31	2	+ 1.9
1019	17 33	67.0	8.3	F 2	F 2	0.40	0.35	0.45	0.55	2 (3)	+ 2.3
1021	17 33	67.3	7.8	F 2	F 2	0.27	0.34	0.62	0.54	2 (3)	+ 3.3
1027	17 37	67.2	8.0	A 2	A 2	0.62	0.66	0.25	0.39	2 (3)	+ 2.5
1052	18 9	67.9	8.0	A 2	A 0	0.66	0.76	0.18	0.20	2 (3)	+ 1.0
1054	18 10	67.8	8.6	F 5	G 0	0.24	0.24	0.55	0.60	1 (2)	+ 4.0
1085	18 37	67.7	7.5	A 0	A 0	0.76	0.86	0.11	0.16	1	+ 1.0
1096	18 47	67.7	7.0	A 0	A 0	0.75	0.91	0.05	0.12	1	+ 1.0
1142	19 19	67.5	8.5	A 0	A 0	0.73	0.77	0.04	0.34	1	+ 2.2
1157	19 29	67.9	8.6	A 2	A 0	0.82	0.82	0.15	0.26	1	+ 1.5
1201	19 46	67.5	8.0	A 5	F 0	0.52	0.59	0.31	0.38	2	+ 2.5
1206	19 51	67.3	9.1	A 5	A 3	0.55	0.50	0.38	0.43	1	
1216	19 58	67.2	7.9	A 2	A 2	0.58	0.70	0.17	0.43	1 (2)	+ 2.5
1227	20 6	67.9	8.8	A 0	—	0.70	0.70	0.02	0.26	1	+ 1.5
1229	20 7	67.8	8.8	F 2	F 2	0.33	0.36	0.53	0.44	1	+ 2.7
1233	20 10	67.9	7.8	F 2	F 2	0.38	0.41	0.56	0.48	2	+ 2.1
1235	20 10	67.9	6.8	B 3	B 3	0.19	0.24		0.18	3 (5)	- 3.0
1248	20 25	67.9	8.8	F 5	F 5	0.20	0.25	0.57	0.54	1	+ 4.1
1267	20 47	67.7	7.1	F 2	F 0	0.36	0.34	0.60	0.52	2 (3)	+ 2.7
1283	21 0	67.8	7.6	B 3	B 5	0.15	0.26		0.31	2	- 3.1
1288	21 6	67.8	6.9	A 2	A 2	0.66	0.76	0.19	0.19	2 (3)	+ 0.9
1295	21 12	67.7	8.4	A 2	A 0	0.68	0.71	0.21	0.33	1 (2)	+ 2.1
1299	21 14	67.9	8.1	F 2	F 0	0.31	0.35	0.56	0.56	1	+ 2.9
1321	21 27	68.2	8.8	A 2		0.70	0.89	0.12	0.24	1	+ 1.3
1322	21 29	67.9	6.8	B 8	B 9	0.72	0.77		0.11	2 (3)	+ 1.0

Cont.

B.D.	α (1900)	δ (1900)	m_{ph}	Sp. U.	Sp. H.	H γ	H δ	K	C	n	M_{ph}
67° 1329	21 ^h 34 ^m	67° .8	6.2	B8	B9	0.34	0.47		0.10	2 (3)	-1.0
1332	21 35	67.7	8.4	B3	B8	0.21	0.32		0.18	3	-2.4
1340	21 38	67.7	8.8	A0	A2	0.70	0.89	0.05	0.18	2	+1.0
1343	21 38	67.9	8.5	A2	A0	0.64	0.70	0.30	0.28	2	+1.7
1357	21 43	67.3	8.2	A0	B9	0.60	0.68	0.04	0.15	3	+0.6
1370	21 51	67.6	8.8	A2	A	0.71	0.87	0.14	0.24	1	+1.3
1371	21 51	68.0	7.3	A2	A0	0.64	0.76	0.14	0.14	1	+0.9
1375	21 52	67.3	7.2	F0	F0	0.42	0.42	0.59	0.44	1	+1.7
1382	21 57	67.5	8.3	F8	F5	0.21	0.23	0.79	0.64	2	+4.2
1384	21 59	67.7	8.5	A0	A0	0.71	0.86	0.11	0.18	2	+1.0
1391	22 2	68.0	9.2	A0	—	0.65	0.90	0.05	0.19	1	+1.0
1393	22 2	67.9	8.6	F2	A2	0.34	0.37	0.69	0.53	1	+2.6
1402	22 5	67.8	7.7	F2	F2	0.32	0.37	0.68	0.54	2	+2.7
1405	22 6	68.0	8.3	F5	F5	0.28	0.33	0.73	0.54	1	+3.2
1409	22 6	67.2	8.4	A0	A0	0.61	0.76	0.04	0.15	2	+0.8
1441	22 26	67.4	9.2	A2	A2	0.68	0.75	0.12	0.31	1	+1.9
1450	22 30	67.9	7.8	A3	A3	0.60	0.70	0.49	0.31	2 (3)	+1.9
1463	22 42	67.6	9.6	B8	A2	0.37	0.44		0.26	1	-1.0
1468	22 46	68.0	6.5	F2	F5	0.29	0.32	0.71	0.59	3	+3.2
1469	22 47	67.8	8.4	B8	B9	0.55	0.61		0.27	1	
1471	22 49	67.5	7.9	F5	F5	0.24	0.26	0.79	0.56	2	+3.9
1475	22 49	67.5	7.4	F2	F2	0.25	0.31	0.56	0.59	2	+3.5
1479	22 51	67.3	9.3	B8	—	0.69	0.74		0.23	1	+1.3
1482	22 52	67.7	8.0	B5	B8	0.33	0.40		0.18	2	-1.3
1485	22 54	67.9	8.3	B5	B8	0.22	0.27		0.26	2	-2.6
1490	22 56	67.4	7.9	B8	A0	0.51	0.60		0.11	2	+0.2
1493	22 58	67.3	8.9	F5	F8	0.17	0.23	0.61	0.56	2	+4.4
1495	22 58	67.9	8.9	B8	—	0.64	0.82		0.14	1	+1.0
1503	23 6	67.9	8.2	B8	B9	0.39	0.52		0.16	2	-0.5
1504	23 6	68.1	8.1	A0	A0	0.65	0.79	0.02	0.14	2	+0.9
1511	23 11	67.3	8.7	B5	—	0.30	0.43		0.18	1	-1.4
1525	23 23	67.3	8.4	A5[A2]	A5	0.49	0.55	0.16	0.47	1	
1542	23 32	67.3	7.2	A2	A0	0.77	0.89	0.19	0.24	4 (8)	+1.3
1546	23 33	67.7	9.3	B0	—	0.22	0.27		0.39	1	-2.6
1547	23 33	67.4	8.5	F0	F5	0.45	0.51	0.56	0.46	2 (5)	
1550	23 34	68.2	9.1	B3	—	0.16	0.16		0.31	1	-3.6
1555	23 37	67.8	8.0	B3	B3	0.20	0.26		0.27	2 (4)	-2.7
1557	23 37	68.1	7.8	A0	A0	0.71	0.86	0.06	0.09	2 (6)	+1.0

Cont.

B.D.	α (1900)	δ (1900)	m_{ph}	Sp. U.	Sp. H.	H γ	H δ	K	C	n	M_{ph}
67° 1561	23 ^h 42 ^m	68° 1	8.8	A 0	A 0	0.72	0.87	0.08	0.18	2 (5)	+1.0
1562	23 43	67.3	5.2	A 0	A 0	0.74	0.87	0.09	0.11	4	+1.0
1570	23 48	67.5	8.8	F 5	F 8	0.21	0.20	0.86	0.66	1 (4)	+4.3
1586	23 55	67.3	8.1	B 8	A 3	0.34	0.42		0.20	1 (4)	-1.2
1588	23 56	67.9	8.0	A 2	A 0	0.65	0.78	0.24	0.34	1 (5)	+2.2
68° 14	0 15	68.3	7.7	F 0	F 2	0.41	0.48	0.55	0.48	2 (4)	
26	0 24	68.5	8.8	A 3	A 2	0.52	0.46	0.26		1	
29	0 25	69.2	7.7	F 5	F 8	0.14	0.22	0.71	0.67	1 (3)	+4.6
32	0 26	68.4	8.8	B 5	—	0.19	0.29		0.35	2	-2.7
33	0 26	68.8	8.3	B 8	A 0	0.73	0.92		0.16	2 (4)	+1.0
35	0 29	69.2	8.6	B 5	B 9	0.36	0.47		0.14	1	-0.9
38	0 31	68.7	8.6	F 5	G 0	0.24	0.23	0.78:	0.53	1	+4.0
49	0 40	68.8	6.7	F 5	F 2	0.28	0.37	0.69	0.55	1	+2.9
56	0 45	68.4	7.9	A 0	A 2	0.71	0.88	0.13	0.25	1	+1.4
57	0 46	68.3	7.0	A 3	A 2	0.56	0.73	0.22	0.30	1 (2)	+1.3
63	0 54	68.8	8.4	B 8	A 0	0.57	0.72		0.10	1	+0.6
64	0 55	68.8	6.7	B 8	B 9	0.64	0.77		0.17	3 (5)	+0.9
68	0 57	68.9	9.2	A 2	A 2	0.56	0.63:	0.34:	0.43	1	+2.5
70	0 59	68.5	8.3	A 0	A 0	0.73	0.90	0.11	0.21	2	+1.1
72	1 0	68.3	8.5	A 2	A 0	0.67	0.76	0.22	0.32	2	+2.0
74	1 2	69.2	7.0	B 3	B 0	0.15	0.17		0.20	3	-3.6
77	1 4	68.2	5.2	A 0	A 0	0.67	0.82	0.05	0.11	4	+1.0
83	1 8	69.1	8.5	A 0	A 0	0.70	0.72	0.11	0.34	2	+2.2
91	1 13	68.6	8.9	B 8	B 8	0.27	0.26		0.18	1	-2.4
93	1 14	68.5	8.7	A 2	A 0	0.77	0.81	0.28	0.33	1	+2.1
122	1 35	68.6	7.9	F 5	F 5	0.15	0.20	0.79	0.72	2	+4.7
137	1 50	68.9	8.9	F 0 [A 2]	F 0	0.44	0.44:	0.14	0.55	1	
140	1 51	69.1	8.8	A 0	A 2	0.62	0.68	0.07	0.34	1	+2.2
144	1 55	69.1	7.6	A 0	A 0 <i>p</i>	0.57	0.79	0.79	0.17	1	+0.8
145	1 56	68.5	7.9	A 2	A 5	0.65	0.78	0.33	0.36	1	+2.3
153	2 5	68.9	8.1	A 0	A 0	0.64	0.77	0.06	0.21	2	+1.1
177	2 30	68.9	8.1	A 0	A 2	0.63	0.80	0.14	0.18	2 (3)	+0.9
189	2 36	68.2	8.0	A 3	A 3	0.55	0.62	0.35	0.46	1 (2)	+2.5
200	2 43	68.5	6.6	F 2	F 5	0.28	0.30	0.75	0.79	1	
208	2 48	68.4	7.9	B 8	B 8	0.35	0.38		0.28	2 (3)	-1.3
209	2 49	68.8	8.0	F 2	F 2	0.29	0.31	0.57	0.56	2 (3)	+3.3
212	2 51	69.1	8.1	A 3	A 2	0.53	0.57	0.26	0.43	2 (3)	+2.5

Cont.

B.D.	α (1900)	δ (1900)	m_{ph}	Sp. U.	Sp. H.	H γ	H δ	K	C	n	M_{ph}
68° 230	3 ^h 8 ^m	69° 1	7.9	A 0	A 0	0.66	0.82	0.06	0.15	2 (3)	+1.0
249	3 19	68.9	7.7	F 8	F 5	0.20	0.28	0.79	0.65	1 (2)	
250	3 20	69.1	7.7	A 0	A 0	0.78	0.88	0.09	0.19	1 (2)	+1.0
256	3 23	68.4	9.1	B 8	A 0	0.37	0.51		0.25	1	-0.7
258	3 26	68.4	8.7	A 5	A 2	0.55	0.61	0.40	0.46	2 (3)	+2.5
286	3 42	68.2	6.1	B 8	B 8	0.53	0.63		0.09	6	+0.3
306	4 2	68.7	9.3	F 2	A 5	0.34	0.38	0.44	0.49	1	+2.5
329	4 20	69.0	8.7	A 2	A 0	0.68	0.80	0.25	0.17	2	+1.0
334	4 24	68.9	8.6	A 2	A 2	0.69	0.80	0.16	0.25	2	+1.4
336	4 27	68.3	8.4	B 5	B 8	0.33	0.33		0.15	2	-1.4
340	4 29	68.9	7.9	A 0	A 0	0.63	0.76	0.13	0.18	2	+0.9
357	4 51	69.0	7.5	F 2	F 5	0.32	0.34	0.68	0.66	2	+2.9
361	4 55	68.8	6.9	F 2	F 2	0.26	0.33	0.56	0.52	2	+3.3
363	4 56	68.1	8.7	A 0	A 0	0.75	0.77	0.11	0.27	2	+1.6
369	5 0	68.4	8.9	A 3	A 2	0.51	0.61	0.34	0.34	2	+2.5
380	5 10	68.5	8.9	F 0	F 8	0.36	0.46	0.42	0.48	1	+1.9
393	5 26	69.0	8.3	F 5	F 5	0.26	0.26	0.69	0.64	2 (3)	+3.8
395	5 27	68.1	9.1	A 5	A 5	0.43	0.50	0.45	0.43	1	
401	5 34	68.8	8.2	F 2	F 5	0.29	0.30	0.72	0.56	2 (3)	+3.3
423	5 58	68.4	8.1	F 0 [A 2]	A 0	0.43	0.50	0.18	0.61	1 (2)	
425	5 59	68.4	7.9	F 2	F 0	0.33	0.43	0.64	0.58	1 (2)	+2.3
426	6 1	68.1	9.2	A 2	A 2	0.75	0.79	0.15	0.22	1	+1.2
435	6 8	68.4	7.9	A 3	A 2	0.66	0.75	0.28	0.32	2	+2.0
442	6 25	68.7	8.7	F 5	F 8	0.27	0.29	0.70	0.56	1	+3.5
454	6 44	68.4	8.0	F 2	F 2	0.33	0.35	0.57	0.56	2	+2.8
456	6 46	68.3	8.0	A 0	B 9	0.57	0.67	0.10	0.17	2	+0.5
462	6 51	68.6	8.7	F 5	F 5	0.17	0.17	0.56	0.59	1	+4.7
468	7 7	68.9	8.7	A 0	A 0	0.64	0.76	0.11	0.19	2	+0.9
470	7 8	68.1	9.2	A 5	A 5	0.39	0.50	0.38	0.36	2	
472	7 10	68.7	8.4	A 5	A 5	0.51	0.53	0.36	0.45	1	
476	7 14	68.1	8.4	F 2	F 5	0.35	0.33	0.56	0.38	1	+2.8
484	7 23	68.6	9.1	A 0	A 0	0.65	0.81	0.04	0.21	1	+1.1
501	7 42	68.1	8.6	B 8	B 9	0.57	0.70		0.07	2	+0.5
518	7 56	68.7	8.3	F 8	F 5	0.13	0.17	0.74	0.57	1	+4.9
533	8 18	68.3	8.2	F 0	F 0	0.47	0.50	0.40	0.44	1	
744	13 45	67.9	8.8	F 8	F 8	0.14	0.21	0.75	0.74	1	+4.6
777	14 18	68.2	7.0	B 8	A 0	0.74	0.96		0.16	2	+1.0
781	14 19	68.3	7.4	A 0	A 2	0.74	0.85	0.10	0.33	3	+2.1

Cont.

B.D.	α (1900)	δ (1900)	m_{ph}	Sp. U.	Sp. H.	H γ	H δ	K	C	n	M_{ph}
68° 787	14 ^h 29 ^m	68° 5	7.4	A 5	A 3	0.49	0.48	0.35	0.52	2	
809	14 53	68.4	8.2	F 5	F 8	0.25	0.28	0.71	0.61	2	+ 3.6
817	15 1	68.3	8.4	F 2	F 8	0.23	0.27	0.61	0.52	2	+ 3.8
823	15 10	68.2	6.6	A 2	A 2	0.59	0.71	0.27	0.33	6	+ 2.1
824	15 10	67.9	9.1	A 5	A 3	0.59	0.71	0.36	0.43	1	+ 2.5
858	15 59	67.9	7.4	F 2	F 2	0.32	0.30	0.70	0.50	1	+ 3.2
864	16 6	68.1	5.5	B 8	A 0	0.69	0.83		0.19	2	+ 1.0
876	16 30	68.9	8.5	F 8	G 0	0.22	0.26	0.70	0.67	2	+ 4.0
880	16 39	68.5	8.6	F 5	G 0	0.21	0.28	0.71	0.55	1	+ 3.9
884	16 46	68.4	9.1	F 0	G 0	0.38	0.44	0.48	0.44	1	+ 1.8
893	16 52	68.1	7.4	A 2	A 0	0.79	0.93	0.25	0.25	2	+ 1.4
904	16 58	68.7	8.9	A 0	—	0.67	—	0.07	0.38	1	+ 2.5
906	16 58	68.8	8.3	A 0	A 0	0.68	0.71	0.06	0.41	1	+ 2.5
908	16 59	68.8	7.6	F 0	A 5	0.44	0.51	0.39	0.41	2	
932	17 29	68.6	8.4	A 2	A 2	0.72	0.82	0.17	0.22	1	+ 1.2
947	17 37	68.4	8.2	F 2	F 5	0.31	0.33	0.67	0.59	2 (3)	+ 3.0
949	17 38	68.8	5.2	F 5	F 5	0.26	0.34	0.66	0.58	3	+ 3.3
961	17 50	68.4	7.7	A 2	A 2	0.61	0.75	0.23	0.20	2 (3)	+ 1.0
963	17 50	68.7	7.1	A 0	A 2	0.55	0.65	0.15	0.39	1	+ 2.5
989	18 18	68.7	6.6	B 8	A 0	0.71	0.91		0.13	1 (2)	+ 1.0
1019	18 46	68.6	7.5	A 0	A 0	0.65	0.76	0.07	0.10	2	+ 0.9
1039	19 1	68.6	8.5	A 0	A 0	0.62	0.79	0.11	0.07	1	+ 0.9
1040	19 3	68.2	6.9	A 2	A 2	0.66	0.82	0.14	0.22	3	+ 1.2
1056	19 17	68.1	8.7	F 2	F 5	0.40	0.41	0.50	0.48	1	+ 1.9
1066	19 28	68.4	8.7	F 0 [A 2]	A 0	0.48	0.46	0.20	0.55	2	
1079	19 44	69.1	5.8	A 0	A 0	0.70	0.82	0.15	0.24	5	+ 1.3
1082	19 47	68.2	6.7	F 2	F 0	0.43	0.48	0.50	0.46	4	+ 1.2
1084	19 51	68.3	8.7	F 0	A 3	0.42	0.46	0.44	0.55	1	+ 1.4
1096	19 58	68.1	7.8	A 3	A 2	0.64	0.77	0.35	0.36	1 (2)	+ 2.3
1097	19 59	68.2	7.9	A 0	B 9	0.69	0.79	0.03	0.11	1	+ 1.0
1137	20 33	68.5	8.5	F 0 [A 2]	A 3	0.58	0.60	0.18	0.42	1 (2)	+ 2.5
1153	20 45	68.5	9.2	A 0	A	0.62	0.78	0.14	0.29	1 (2)	+ 1.8
1180	21 5	68.9	8.9	A 2	A 2	0.71	0.78	0.18	0.23	1 (2)	+ 1.3
1188	21 6	68.2	8.1	A 5	A 3	0.45	0.48	0.33	0.38	2 (3)	
1195	21 15	68.5	8.7	A 0	A	0.62	0.85	0.09	0.24	1 (2)	+ 1.3
1206	21 19	69.1	7.7	F 0	A 5	0.45	0.50	0.43	0.42	1 (2)	
1207	21 19	69.0	8.8	A 0	—	0.50	0.81	0.05	0.44	1	+ 2.5
1214	21 22	69.1	6.8	B 8	B 8	0.35	0.49		0.11	1	— 0.9

Cont.

B.D.	α (1900)	δ (1900)	m_{ph}	Sp. U.	Sp. H.	H γ	H δ	K	C	n	M_{ph}
68° 1223	21 ^h 31 ^m	68° 3	9.2	A 2	A	0.71	0.78	0.19	0.28	1	+1.7
1225	21 31	68.3	8.4	A 2	A 2	0.65	0.73	0.36	0.33	2	+2.1
1252	21 46	68.9	8.9	F 0	—	0.40	0.46	0.60	0.46	1	+1.5
1266	21 58	68.6	8.9	A 0	A 0	0.70	0.80	0.09	0.31	1	+1.9
1286	22 9	68.4	8.0	A 0	A 0	0.54	0.65	0.04	0.10	3	+0.4
1287	22 10	68.5	7.2	A 0	A 0	0.78	0.86	0.07	0.16	3	+1.0
1293	22 16	68.2	8.8	F 2	F 5	0.30	0.35	0.58	0.48	2	+3.0
1295	22 18	68.9	8.0	F 8	F 5	0.16	0.21	0.84	0.60	3	+4.5
1298	22 20	69.1	8.1	A 2	A 2	0.63	0.83	0.16	0.22	3	+1.2
1303	22 23	68.5	7.1	F 0	F 0	0.51	0.60	0.58	0.49	3	
1315	22 32	68.8	8.6	F 0	F 0	0.34	0.39	0.61	0.51	1	+2.5
1316	22 33	68.5	8.4	A 3	A 3	0.57	0.64	0.27	0.35	1	+2.2
1319	22 34	68.7	7.4	F 0 [A 3]	$\begin{cases} A 3 \\ G \end{cases}$	0.47	0.52	0.32	0.49	2	
1325	22 38	68.8	9.2	B 8	A 0	0.43	0.54		0.24	1	-0.4
1330	22 43	68.9	8.3	B 8	A 0	0.51	0.56		0.17	1	0.0
1353	23 2	68.7	9.1	A 3	—	0.56	0.67	0.32	0.34	1	+2.2
1373	23 19	68.5	9.3	B 5	—	0.12	0.33		0.42	1	-2.9
1375	23 20	68.7	8.7	A 2	—	0.73	0.86	0.26	0.40	1	+2.5
1391	23 39	68.5	8.5	F 0	F 5	0.39	0.44	0.47	0.54	2 (4)	+1.8
1393	23 40	69.2	7.0	B 5	B 8	0.31	0.46		0.09	3 (4)	-1.2
1402	23 46	68.9	8.5	F 5	F 8	0.27	0.30	0.77	0.57	1 (3)	+3.4
1414	23 54	68.8	8.2	F 2	F 0	0.41	0.43	0.66	0.48	1 (3)	+1.7
1426	0 0	68.3	6.8	A 0	B 9	0.65	0.93	0.03	0.11	1 (2)	+1.0
69° 29	0 31	70.0	8.6	F 5	F 8	0.19	0.24	0.76	0.62	1	+4.2
32	0 34	70.2	7.1	A 0	A 0	0.71	0.97	0.05	0.18	1 (2)	+1.0
46	0 44	70.2	6.8	B 8	B 9	0.39	0.66		0.14	1 (3)	-0.1
55	0 52	69.9	6.8	B 8	B 9	0.47	0.59		0.08	2	0.0
61	0 55	69.9	8.0	F 2	F 5 A 5	0.43	0.45	0.56	0.57	1	+1.4
63	0 56	69.8	8.2	A 0	A 0	0.78	0.89	0.07	0.27	2	+1.6
70	1 2	70.1	7.4	B 8	A 0	0.62	0.79		0.21	2	+1.1
100	1 24	70.1	8.7	A 2	A 0	0.59	0.69	0.19	0.53	1	+2.5
102	1 24	69.8	6.0	F 5	F 5	0.22	0.26	0.64	0.61	2	+4.0
103	1 25	69.5	6.8	B 8	B 9	0.44	0.62		0.16	3 (5)	-0.1
113	1 35	69.7	8.2	F 8	F 8	0.19	0.21	0.83	0.66	2	+4.4
114	1 35	70.1	5.2	A 0	A 0	0.66	0.83	0.03	0.15	4	+1.0
144	2 14	69.9	8.1	F 5	F 5	0.25	0.29	0.42	0.61	1	+3.6

Cont.

B.D.	α (1900)	δ (1900)	m_{ph}	Sp. U.	Sp. H.	H γ	H δ	K	C	n	M_{ph}
69° 157	2 ^h 24 ^m	69° 7	8.2	F2	F5	0.34	0.42	0.48	0.51	2 (3)	+2.3
158	2 24	69.8	8.4	F0	F0	0.41	0.48	0.52	0.56	1	+1.4
160	2 26	69.4	9.7	B8	A0	0.54	0.66		0.26	1	
171	2 33	69.3	7.4	B8	B8	0.40	0.49		0.13	1 (2)	-0.6
179	2 40	69.2	var.	A2	A0	0.68	0.79	0.16	0.34	1	+2.2
196	2 58	69.8	8.4	A5	A5	0.51	0.57	0.43	0.47	1 (2)	
199	2 59	69.4	8.2	A0	A0	0.69	0.89	0.10	0.26	2 (3)	+1.5
203	3 7	69.6	7.4	A0	A0	0.72	0.88	0.07	0.16	2 (3)	+1.0
205	3 10	69.4	6.6	A0	A0	0.72	0.84	0.10	0.19	2 (4)	+1.0
222	3 33	69.5	7.0	A3	A3	0.65	0.70	0.39	0.40	4	+2.5
225	3 37	69.9	8.3	F0	F0	0.34	0.43	0.50	0.48	2	+2.3
235	3 58	69.6	8.5	B8	A0	0.71	0.80		0.21	1	+1.1
255	4 19	69.9	9.1	A2	A2	0.67	0.79	0.22	0.35	1	+2.2
267	4 32	69.7	8.4	A0	B9	0.72	0.88	0.06	0.21	1	+1.1
273	4 38	69.6	8.3	A0	A0	0.66	0.87	0.05	0.21	1	+1.1
280	4 43	69.9	8.9	A0	A0	0.57	0.71	0.11	0.13	1	+0.6
285	4 48	69.1	8.5	A0	A0	0.60	0.74	0.12	0.26	2	+1.5
286	4 49	69.9	8.7	F0	G0	0.34	0.47	0.34	0.45	1	+2.0
288	4 49	69.8	7.8	A2	A0	0.73	0.82	0.17	0.29	2	+1.8
290	4 50	69.3	8.9	A0	A0	0.65	0.86	0.13	0.24	2	+1.3
301	4 58	69.7	8.1	A0	B9	0.69	0.85	0.08	0.18	2	+1.0
304	5 0	69.9	8.7	A3	A0	0.38	0.43	0.32	0.38	2	+2.0
315	5 12	69.3	8.7	F2	F2	0.34	0.37	0.61	0.45	1	+2.6
317	5 13	69.5	8.6	A5	A5	0.56	0.63	0.39	0.36	1 (2)	+2.3
325	5 19	69.4	8.4	B8	A0	0.51	0.63		0.16	1 (2)	+0.2
327	5 23	69.6	8.2	F5	F5	0.19	0.26	0.62	0.64	2 (3)	+4.1
350	5 47	69.6	7.2	F0	F0	0.45	0.52	0.50	0.54	3 (4)	
368	6 6	69.5	7.7	A0	A0	0.70	0.86	0.10	0.18	2 (3)	+1.0
371	6 8	69.4	4.8	A0	A0	0.85	1.05	0.08	0.25	4	+1.4
373	6 9	69.6	6.8	A5	A5	0.51	0.57	0.52	0.42	2 (3)	
385	6 26	69.4	8.4	A2	A5	0.56	0.63	0.20	0.43	2	+2.5
389	6 36	69.7	8.1	B8	A0	0.65	0.83		0.18	1	+1.0
394	6 43	69.0	5.1	B8	B5	0.35	0.54		0.14	2	-0.6
402	6 54	69.0	8.4	F8	F8	0.17	0.23	0.76	0.60	2	+4.4
438	7 37	69.4	7.1	F0	F0	0.42	0.55	0.46	0.44	2	
440	7 40	69.2	8.8	A0	A0	0.56	0.65	0.21	0.32	2	+2.0
448	7 47	69.0	8.9	F0	F0	0.39	0.47	0.48	0.37	1	+1.5
462	8 12	69.3	8.5	F5	F2	0.22	0.30	0.74	0.47	1	+3.8

Cont.

B.D.	α (1900)	δ (1900)	m_{ph}	Sp. U.	Sp. H.	H γ	H δ	K	C	n	M_{ph}
69° 464	8 ^h 14 ^m	69° 2	7.3	F5	F5	0.26	0.32	0.67	0.58	1	+3.4
470	8 21	68.8	7.1	A0	A0	0.60	0.67	0.07	0.11	1	+0.6
716	13 42	69.7	8.3	F5	F5	0.17	0.29	0.71	0.62	1	+4.1
726	13 51	69.7	8.4	A5	A3	0.54	0.56	0.40	0.44	1	
741	14 16	69.2	7.7	F2	F2	0.33	0.34	0.64	0.54	2	+2.8
743	14 16	69.7	8.4	F2	F2	0.28	0.29	0.66	0.56	2	+3.4
789	15 14	69.3	6.5	A0	A0	0.61	0.79	0.10	0.20	4	+1.0
799	15 30	69.5	8.8	A2	A2	0.52	0.64	0.20	0.42	2	+2.5
808	15 38	69.1	7.8	F2	F5	0.23	0.29	0.67	0.56	2	+3.8
812	15 44	68.9	7.2	A3	A2	0.68	0.84	0.27	0.35	3	+2.2
813	15 47	69.8	7.4	A2	A2	0.69	0.82	0.33	0.33	2	+2.1
825	15 53	69.0	7.2	F5	F5	0.19	0.25	0.72	0.63	1	+4.2
850	16 28	68.9	4.9	B8	B8 p	0.63	0.79		0.14	2	+0.9
860	16 38	69.4	7.8	A5	F0	0.51	0.61	0.44	0.45	1	
872	16 48	69.3	7.4	A0	A0	0.71	0.85	0.12	0.19	2	+1.0
877	16 50	69.1	8.4	A2	A2	0.64	0.78	0.26	0.28	1	+1.7
891	17 4	69.9	8.2	F2	F5	0.19	0.35	0.65	0.59	1	+3.6
911	17 22	69.9	7.9	F5	F8	0.23	0.30	0.65	0.69	1	+3.7
938	17 40	69.2	8.6	A0	A0	0.69	0.80	0.08	0.29	1 (2)	+1.8
939	17 41	69.2	7.3	F2	F2	0.29	0.30	0.68	0.54	2 (3)	+3.3
946	17 45	69.1	8.2	F8	F8	0.17	0.24	0.72	0.71	1 (2)	+4.4
951	17 51	69.2	8.5	A2	A2	0.70	0.77	0.26	0.31	1 (2)	+1.9
974	18 19	69.9	8.0	F2	F5	0.29	0.33	0.57	0.55	1 (2)	+3.2
977	18 22	70.0	8.0	F8	G0	0.16	0.21	0.51	0.59	1 (2)	+4.5
988	18 33	69.9	8.4	A2	A0	0.66	0.76	0.16	0.08	1	+0.9
1018	18 59	69.4	6.1	B8	B9	0.39	0.48		0.09	2 (4)	-0.7
1034	19 12	69.2	8.6	A5	A5	0.53	0.57	0.42	0.50	1	+2.5
1057	19 35	70.0	7.7	A0	A0	0.62	0.69	0.09	0.19	2	+0.7
1067	19 44	69.2	8.6	A5	F0	0.42	0.44	0.42	0.51	2	
1069	19 46	69.7	8.2	A2	A0	0.60	0.68	0.19	0.35	2	+2.2
1086	19 59	69.1	7.4	A0	A0	0.75	0.81	0.14	0.27	2	+1.6
1099	20 22	69.2	7.1	A3	A3	0.72	0.81	0.42	0.33	2 (3)	+2.1
1110	20 32	70.1	8.4	A2	A0	0.59	0.67	0.29	0.43	2 (3)	+2.5
1120	20 41	69.5	8.9	A2	A	0.54	0.63	0.30	0.41	1 (2)	+2.5
1122	20 43	69.3	8.7	A3	A2	0.54	0.64	0.29	0.48	1 (2)	+2.5
1129	20 46	69.6	7.7	A0	A0	0.69	0.84	0.05	0.14	2 (3)	+1.0
1130	20 48	69.3	7.3	A2	A0	0.66	0.82	0.24	0.34	2 (3)	+2.2
1166	21 23	69.6	7.7	A0	A0	0.76	0.84	0.07	0.23	1 (2)	+1.3

Cont.

B.D.	α (1900)	δ (1900)	m_{ph}	Sp. U.	Sp. H.	H γ	H δ	K	C	n	M_{ph}
69° 1173	21 ^h 27 ^m	70° .1	2.5	B 3	B 1	0.18	0.22		0.04	4	−3.1
1178	21 30	69.2	8.3	A 3	A 2	0.54	0.61	0.87	0.30	2 (3)	+1.8
1189	21 37	70.0	8.4	F 5	F 8	0.18	0.22	0.73:	0.74	1	+4.4
1191	21 40	69.2	7.8	A 0	A 0	0.71	0.88	0.09	0.20	3	+1.0
1193	21 43	69.5	8.5	F 2	F 2	0.34	0.36	0.50	0.50	2	+2.7
1198	21 45	69.7	6.2	A 0	A 0	0.59	0.84	0.04	0.14	2	+0.9
1204	21 51	69.2	7.2	A 2	A 2	0.61	0.79	0.22	0.23	3	+1.3
1212	21 58	69.9	8.8	F 0	F 2	0.36	0.41	0.64	0.51	1	+2.3
1216	22 2	69.7	8.9	F 8	G 5	0.18	0.26	0.71:	0.82	1	
1219	22 5	69.7	8.4	B 8	A 0	0.54	0.72		0.17	2	+0.5
1221	22 5	70.2	7.0	B 8	A 0	0.48	0.63		0.24	2	0.0
1224	22 6	69.5	8.0	A 0	A	0.73	0.87	0.07	0.15	3	+1.0
1225	22 6	69.5	7.8	A 0	A 0	0.73	0.89	0.05	0.18	3	+1.0
1226	22 7	69.7	8.0	F 5	F 2	0.23	0.25	0.68	0.48	2	+4.0
1228	22 8	69.6	5.7	F 2	F 2	0.32	0.36	0.56	0.54	4	+2.8
1229	22 9	69.9	8.3	F 0	F 0	0.34	0.45	0.43	0.44	1	+2.0
1230	22 10	69.4	8.8	A 2	A 0	0.64	0.72	0.31	0.39	2	+2.5
1232	22 11	69.6	8.1	B 8	A 0	0.48	0.62		0.14	2	+0.1
1237	22 14	69.4	8.3	B 8	A 0	0.55	0.66		0.18	2	+0.4
1245	22 19	69.8	7.7	A 0	A 0	0.69	0.88	0.11	0.20	3	+1.0
1253	22 26	70.1	8.8	F 8	G 0	0.15	0.28	0.67	0.59	1	+4.2
1256	22 27	69.9	7.2	A 3	A 2	0.60	0.71	0.44	0.36	4	+2.3
1257	22 27	69.7	7.0	B 5	B 5	0.34	0.45	0.03	0.13	3 (5)	−1.1
1262	22 30	69.4	6.0	F 2	F 2	0.40	0.47	0.43	0.48	4	+1.5
1263	22 30	69.9	6.0	A 0	A 0	0.64	0.78	0.06	0.12	4	+0.9
1264	22 30	69.6	8.4	F 0	F 0	0.43	0.48	0.46	0.41	1	
1267	22 32	69.9	9.1	A 2	A 2	0.72	0.80	0.22	0.27	1	+1.6
1288	22 52	69.8	7.5	F 0	A 5	0.44	0.49	0.49	0.42	2	
1292	22 56	70.2	8.6	A 2	A 2	0.62	0.79	0.14	0.34	2	+2.2
1294	22 57	69.3	8.7	A 2	A 2	0.60	0.71	0.22	0.34	2	+2.2
1303	23 1	70.1	8.6	F 2	G 0	0.34	0.32	0.52	0.60	2	+2.9
1331	23 22	70.1	6.8	A 2	A 2	0.51	0.60	0.17	0.47	2	
1332	23 23	69.8	5.6	A 2	A 2	0.62	0.80	0.31	0.28	3	+1.7
1342	23 34	70.1	8.4	A 2	A 3	0.53	0.63	0.34	0.47	2	+2.5
1377	23 58	69.7	7.9	B 8	A 0	0.63	0.79		0.13	1 (3)	+0.9
1379	23 59	70.2	8.6	A 0	A 0	0.55	0.84:	0.05	0.36	1	+2.3

Cont.

B.D.	α (1900)	δ (1900)	m_{ph}	Sp. U.	Sp. H.	H γ	H δ	K	C	n	M_{ph}
70° 219	2 ^h 54 ^m	70° .3	8.4	A 0	A 0	0.56	0.85	0.20	0.24	1	+1.8
262	3 41	70.2	7.5	A 3	A 3	0.53	0.58	0.34	0.49	2	+2.5
274	3 56	70.2	8.7	B 8	B 9	0.62	0.83		0.20	1	+1.0
305	4 24	70.1	8.0	A 2	A 0	0.68	0.80	0.11	0.30	2	+1.8
351	5 16	70.1	7.2	B 8	B 9	0.60	0.78	0.04	0.19	1 (2)	+0.8
362	5 27	70.3	6.7	B 8	A 0	0.51	0.71		0.19	1 (4)	+0.5
402	6 19	69.9	8.4	B 8	A 0	0.55	0.79	0.05	0.15	2	+0.7
427	6 46	70.2	8.2	A 0	A 0	0.65	0.77	0.11	0.24	2	+1.3
450	7 13	70.1	9.1	F 2	F 0	0.29	0.33	0.55	0.49	1	+3.2
496	7 59	70.5	8.4	A 2	A 0	0.58	0.63	0.13	0.32	1	+2.0
497	7 59	70.0	7.0	F 8	F 8	0.17	0.16	0.74	0.61	1	+4.7
760	13 48	70.1	8.2	B 8	A 0	0.74	0.84		0.37	1	+2.4
774	14 8	70.1	7.2	B 8	B 9	0.72	0.81		0.19	2	+1.0
826	15 8	70.5	8.4	F 8	G 5	0.17	0.24	0.57	0.79	1	
827	15 8	70.0	7.3	F 0	F 2	0.41	0.49	0.48	0.51	2	+1.3
863	16 5	70.5	7.0	A 2	A 0	0.62	0.77	0.12	0.57	1	+2.5
887	16 37	69.9	8.1	F 0	F 5	0.31	0.47	0.54	0.56	1	+2.3
888	16 38	70.0	8.1	A 5	F 0	0.52	0.56	0.36	0.47	1	
894	16 41	70.4	8.2	F 0 [A 2]	A 2	0.42	0.43	0.12	0.67	1	
1020	18 44	70.5	7.7	A 0	A 0	0.51	0.76	0.09	0.24	1	
1102	20 2	70.2	8.0	A 2	B 9	0.61	0.79	0.21	0.30	1	+1.8
1105	20 7	70.4	8.1	F 2	F 0	0.37	0.43	0.48	0.50	1	+2.0
1126	20 32	70.2	6.7	B 8	A 0	0.60	0.70		0.24	2	+1.3
1312	23 12	70.3	8.2	A 0	A 0	0.26:	0.52	0.11	0.30	1	-1.2

Catalogue II.

Stars in the Pleiades.

Trumpler No.	α (1900)	δ (1900)	Sp. U.	$m_{ph.}$	H γ	H δ	K	C	n
414 *	3 ^h 41 ^m .5	+ 23° 48'	B 8 τ —	2.8	0.34	0.42		0.03	9 (4)
594 *	43.2	23 45	B 8 τ —	3.6	0.38	0.48		0.10	4
148 *	38.9	23 48	B 8 τ —	3.6	0.37	0.46		0.06	9 (6)
170 *	39.2	24 9	B 8 τ —	4.2	0.42	0.51		0.05	14 (6)
506 *	42.4	23 7	B 8 σ +	5.4	0.48	0.56		0.09	14 (8)
139 *	38.8	23 58	A 0 σ —	5.3	0.47	0.59		0.10	10 (8)
166 *	39.2	24 31	B 8 σ	5.7	0.50	0.58		0.09	9 (7)
S 149	44.0	21 56	A 0 σ	6.0	0.50	0.59		0.11	7 (6)
671 *	43.8	23 24	A 0 σ —	6.0	0.57	0.66		0.06	8 (6)
240 *	39.9	24 14	A 0 σ —	5.7	0.57	0.68		0.09	8 (6)
247 *	40.1	24 13	A 0 ρ	6.3	0.63	0.75		0.12	7 (5)
354 *	41.0	24 13	B 8 ρ	6.7	0.67	0.79		0.13	7 (5)
622 *	43.4	24 4	B 8 ρ	6.5	0.64	0.79		0.09	7 (5)
S 23	32.8	22 20	A 0 κ —	6.7	0.74	0.84		0.14	8 (6)
413 *	41.5	23 59	A 0 μ	6.8	0.72	0.79		0.18	4
697 *	44.0	23 33	A 0 μ	6.8	0.66	0.79		0.17	8 (6)
397 *	41.4	23 30	A 0 κ —	6.9	0.75	0.82		0.16	6 (3)
234 *	39.9	22 50	A 0 κ —	6.9	0.72	0.88		0.21	6 (3)
S 142	43.7	22 14	A 0 μ	6.9	0.79	0.86		0.16	6 (3)
791 *	44.9	23 39	A 0 κ —	7.0	0.69	0.83		0.19	6 (3)
S 25	33.2	24 23	A 0 κ —	7.1	0.82	0.92		0.19	6 (3)
215 *	39.7	24 1	A 0 κ —	7.3	0.67	0.79		0.20	5 (2)
295 *	40.5	23 57	A 2 κ —	7.4	0.75	0.85		0.23	5 (3)
688 *	44.0	24 3	A 0 κ —	7.5	0.80	0.96		0.18	3
311 *	40.6	23 19	A 0 κ	8.5	0.72	0.77		0.34	2
518 *	42.5	24 2	A 2 κ —	7.0	0.74	0.81		0.25	6 (3)
742	44.5	24 11	A 2 κ —	7.5	0.65	0.80		0.25	3
613 *	43.8	24 5	A 2 κ —	7.6	0.75	0.92		0.25	2
47 *	37.7	24 46	A 2 κ —	7.7	0.76	0.87		0.26	2
S 165	45.9	25 42	A 2 κ —	7.9	0.81	0.95	0.18	0.25	2
629 *	43.5	23 57	A 2 κ —	8.1	0.73	0.77	0.23	0.34	2
410 *	41.5	23 22	A 2 κ —	7.9	0.71	0.77	0.21	0.30	2
S 137	43.3	22 18	A 2 κ	7.9	0.72	0.84	0.21	0.37	2

Cont.

Trumpler No.	α (1900)	δ (1900)	Sp. U.	$m_{ph.}$	H γ	H δ	K	C	n
235 *	3 ^h 39 ^m .9	+ 23° 44'	A 2 κ —	8.0	0.67	0.74	0.15	0.31	2
S 84	40.0	25 5	A 3 κ	8.3	0.69	0.80	0.33	0.35	2
195 *	39.5	23 43	A 2 κ	8.2	0.63	0.77	0.23	0.34	2
74 *	38.0	24 14	A 3 κ	8.2	0.69	0.77	0.25	0.28	2
S 115	41.8	25 5	A 3 κ	8.5	0.70	0.75	0.45	0.28	2
51 *	37.8	24 3	A 5 κ	8.4	0.62	0.67	0.32	0.39	2
359 b*	41.1	24 31	F 0 [A 2]	9.0	0.52	0.56	0.44	0.43	2
50 *	37.8	23 20	A 5 κ	8.3	0.56	0.57	0.36	0.46	2
121 *	38.5	24 5	F 0 [A 2]	8.4	0.53	0.53	0.34	0.36	2
S 108	41.5	22 37	A 5 [A 2]	8.6	0.63	0.70	0.18	0.36	2

Summary.

The present spectrophotometric investigation deals primarily with 882 B, A and F type stars in the Greenwich polar zone. Besides these, 43 Pleiades stars and 15 bright F type stars scattered over the north celestial hemisphere have been studied.

Short objective prism spectra have been used and the plates have been calibrated by the prism-crossed-by-grating method. The spectra have been widened by micrometric displacement of the plates.

The measurements have been performed by means of a Schilt photometer with an about 20 Å wide rectangular diaphragm. By the measurement of the stronger spectral lines with such a diaphragm a measure of the total absorption in the lines is obtained. This method of measuring spectral lines has been carefully tested and established to be very accurate and convenient.

The spectral lines studied are $H\gamma$, $H\delta$ and K . In connection with the line intensity work the magnitude difference between $\lambda 3912$ and $\lambda 4415$ has been measured. This quantity has proved to be a good colour-equivalent.

The diagram giving the relationship between hydrogen line intensity and colour shows a very characteristic shape. The points form a curve similar to a Gaussian one but abnormally steep on the high temperature side.

The intensity of the hydrogen lines has, together with the colour, established a good criterion of luminosity for B, A and F type stars. On the high temperature side increasing line intensity corresponds to decreasing luminosity, on the low temperature side the relationship is opposite. For stars of maximum hydrogen line intensity increasing colour is accompanied by decreasing luminosity.

For the bright Pleiades stars the relation between hydrogen line intensity and luminosity deviates considerably from that valid for ordinary stars.

Most of the B stars show an abnormally high colour. The reason for this has been found to be a selective absorption in space appearing in small galactic latitudes. The absorption of $\lambda 3912$ relative to $\lambda 4415$ has been found to be 0.19 magnitudes per 1000 parsecs.

A break is suggested in the spectral sequence at about the type A 5. The break is noticeable in colour, star density, luminosity and the distribution of velocities.

The relative intensity of $H\gamma$ and $H\delta$ shows a slight shift when proceeding from high temperature stars to low temperature stars.

The K -line has been found a useful measure of temperature though not so significant as is generally believed.

The absolute magnitudes have been determined for most stars from the measured hydrogen line intensities and colours.

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